HAMILTON LAKE ASSOCIATION

A SPLASH of SUNSHINE

T BY 2000

SAVING SOIL

FEASIBILITY STUDY

Lake Enhancement

Hamilton Lake, Indiana

The photograph of Hamilton Lake was taken on June 2, 1989 following a rain storm. The muddy areas in the lake indicate that Black Creek (entering at upper right) and Jackson Judson Creek (entering the bay on left) are significant sources of sediment to Hamilton Lake.

HARZA ENGINEERING COMPANY

HAMILTON LAKE ENHANCEMENT FEASIBILITY STUDY

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HAMILTON LAKE ENHANCEMENT PROJECT
Feasibility Study

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GLOSSARY OF TECHNICAL TERMS

Anoxia	A condition of no oxygen in the water. Often occurs near the bottom of fertile stratified lakes in the summer and under ice in late winter.
Alkalinity	The buffering capacity of water.
Coliform bacteria	A group of microorganisms that is the principal indicator of the suitability of water for domestic or other uses and the sanitary quality of that water.
Epilimnion	Uppermost, warmest, layer of a lake during summertime thermal stratification. The epilimnion extends from the surface to the thermocline.
Eutrophic	Waters with a good supply of nutrients and hence high organic production.
Eutrophication	The process of lake aging, involving physical, chemical, and biological changes associated with nutrient, organic matter, and silt enrichment of a lake. If the process is accelerated by man-made influences, it is termed cultural eutrophication.
Hypolimnion	Lower, cooler layer of a lake during summertime thermal stratification.
Kjeldahl nitrogen	Organic nitrogen plus ammonia nitrogen.
Macrophytes	Rooted and floating aquatic plants, commonly referred to as waterweeds.
Mesotrophic	Waters moderately rich in plant nutrients.
Non-point source pollution	Pollutants that do not originate from a pipe or single source.
Oligotrophic	Waters with a small supply of nutrients and hence low organic productivity.
Orthophosphorus	A simple form of phosphorus that is readily available for uptake by plants.

Pheophytin	A product formed by the breakdown of chlorophyll, the primary plant pigment responsible for photosynthesis.
Phytoplankton	Microscopic algae that float freely in open waters.
Fecal streptococci	A group of organisms indicative of fecal pollution from warm blooded animals.
Thermocline	A horizontal plane across a lake at the depth of the most rapid vertical change in temperature and density in a stratified lake; the transition zone between the epilimnion and the hypolimnion.
Wetland	Areas that are unundated or saturated by surface or ground water, with vegetation adapted to living in saturated soil conditions. Generally includes swamps, marshes, bogs, and similar areas.

EXECUTIVE SUMMARY

This lake enhancement feasibility study included acquisition and review of existing information on Hamilton Lake and its watershed, water quality investigations, land use mapping and nonpoint source phosphorus modelling of the watershed, and identification and evaluation of lake enhancment techniques.

The lake as well as streams draining the largest subbasins were sampled for water quality. Hamilton Lake water quality is moderately alkaline and fertile. Water clarity on the day of sampling (Aug 1, 1989) was low; secchi disk visibility was 3.4 feet. This rather low clarity was largely due to the high numbers of phytoplankton in the water. Plankton numbers were high, due to the nutrient concentrations in the water and the season of sampling. Hamilton Lake is legally designated for recreational use (including whole-body contact recreation) and support of warm-water aquatic life. Hamilton Lake likely stays within the standards during the recreational season; however, as evidenced by a Black Creek water sample taken after a rain storm on July 27, 1989, the lake may not meet the bacteriological standards after storms because of watershed sources of coliform bacteria. Mean water column total phosphorus was 0.05 mg/L, of which about 20% was ortho-phosphate. Hypolimnetic (deep) waters of Hamilton Lake were much richer in nutrients than the epilimnion (surface water). A large fraction of these higher concentrations of nutrients in the hypolimnion represent nutrients that are "recycled" on an annual basis.

The 9,681-acre watershed was divided into nine subbasins for detailed study. Land use and highly erodible lands were mapped. Grasslands, either in the form of Conservation Reserve "set aside" lands, hayfields, or idle lands are the most common land use, at 36% of the watershed. Crop land is second, at 23%. Highly erodible soils, particularly those actively farmed for production of row crops, can be a significant source of sediment to Hamilton Lake. About 61 % of the lake's total watershed is considered to be highly erodible land; about 15% of this highly erodible land is being used for row crop production. Black Creek's drainage area contains about 56% of the highly erodible soils in the watershed. A relatively high fraction (75%) of the Black Creek drainage is highly erodible land that is being used for row crop production.

Based upon the water quality and plankton studies, the Department of Environmental Management's (IDEM) lake eutrophication index (LEI) was updated. In the mid-1980's, IDEM computed an LEI of 31; this study's updated LEI is 28. The reduction from 31 to 28 eutrophy points does not change Hamilton Lake's classification as a Class 2 lake. Class 2 lakes are of intermediate quality. Class 2 lakes are productive, moving slowly towards senescence, are impacted by anthropogenic activities, and may have problems with aquatic weeds and plankton.

This study estimated lake phosphorus (P) loadings from nonpoint sources and the resulting mean annual water column phosphorus concentrations using an empirical model. No point sources of phosphorus were found in the watershed. The phosphorus model predicted a mean annual water column average total phosphorus concentration of 0.044 mg/L, indicative of a eutrophic lake. Row crops being produced on highly erodible lands represent the single largest source of phosphorus to Hamilton Lake and are about 45% of the total phosphorus loading. Grassland, because of its abundance in the watershed, is the second largest source of phosphorus to the lake, at 25% of the total. Row crops on non-highly erodible soils are third, representing about 22% of the total. Other sources are essentially negligible. The Black Creek watershed contributes about two-thirds of the annual phosphorus loadings to the lake.

Based upon the above lake and watershed studies, alternative methods for enhancing Hamilton Lake were evaluated using a three-level screening procedure, with the depth of study increasing as the list of alternatives narrows to those most feasible. The evaluation system's three levels were: Initial Identification and General Screening; General Screening; and, Feasibility Evaluation. Lake enhancement techniques remaining for evaluation at the most detailed level of study included harvesting and herbicide application for control of aquatic macrophytes; phosphorus inactivation, hypolimnetic aeration, and artificial circulation for in-lake control of phosphorus concentrations; and construction of wetlands for watershed control of sediment and phosphorus loading of the lake.

In the near term, it is recommended that the Hamilton Lake Association apply to the "T by 2000" Program for financing to design and construction a series of wetlands in the watershed to trap sediments and their associated nutrients before they reach the lake, and, to switch from herbicides to harvesting to control macrophytes. Herbicides should be used only where the harvester cannot cut and remove the weeds. Harvesting is estimated to cost $135,000 the first year, and $45,000 annually in succeeding years. Construction of eight wetlands is estimated to cost $500,000; after ten years, these wetlands will still have more than 90% of their design sediment storage capacity. After these two recommendations have been implemented, the Lake Association should then investigation the additional improvements in water quality obtainable from a phosphorus inactivation project.

INTRODUCTION

Background

In autumn of 1988, the Hamilton Lake Association approached the Indiana Department of Natural Resources (DNR) for technical and financial lake enhancement assistance. The lake association was given a grant under the DNR's "T by 2000" lake enhancement program. The grant funds were used to procure the services of a consulting engineer to perform a lake enhancement feasibility study.

Objectives

The lakeside residents and users of Hamilton Lake have expressed concern to the DNR for several years about the proliferation of aquatic macrophytes (or weeds) in the lake. In areas where they are abundant, the macrophytes hinder recreational use of the lake by fouling fishing lines and boat propellers, and causing a general aesthetic nuisance. Past weed control programs (i.e. herbicide applications) have been successful but are expensive and represent only a short-term solution. Residents have also noticed a gradual degradation of water quality in terms of decreased water clarity.

The specific objectives of this lake enhancement feasibility study were:

1. To define the sources of problems within Hamilton Lake and the watershed that contribute to eutrophication and sedimentation in the lake,

2. To identify technically feasible measures to restore the ecological integrity and recreational value of Hamilton Lake,

3. To recommend appropriate measures from the alternative lake restoration techniques identified, based upon engineering feasibility, cost effectiveness, and environmental compatibility.

Scope of the Study

The feasibility study involved five tasks:

1. Data Acquisition and Review. Existing data on Hamilton Lake ecology were collected and reviewed for use in this study.

2. Field Investigations. Water and sediment quality testing was performed; aquatic vegetation in the lake was surveyed and identified.

3. Assessment of Existing Conditions. A map and tally of watershed land use were prepared; nonpoint source phosphorus loading to the lake was estimated; a new lake eutrophication index was computed.

4. Study of Alternatives. Identification, description, screening, cost estimating and recommendation of lake enhancement measures.

5. Report and Presentation.

Acknowledgements

We appreciate the assistance given to the study team by the Hamilton Lake Association. Particularly valuable was the field sampling help, and enthusiasm throughout the study of the Lake Association's President, Mr. Mark Morton. Mr. Robert Frazier graciously allowed reprinting of his photograph of Hamilton Lake on the cover.

Several agencies provided important data for this study: the DNR's Divisions of Fish and Wildlife, Nature Preserves, and Soil Conservation; the Department of Environmental Management; the Steuben County Soil Conservation Service and Agricultural Stabilization and Conservation Service; and the Steuben County Surveyor. The assistance of each of these agencies is appreciated.

The draft report was reviewed by several anonymous individuals, and their comments are appreciated.

PHYSICAL DESCRIPTION OF THE STUDY AREA

Location

Hamilton Lake is a natural lake located in Otsego Township in the southern part of Steuben County, Indiana (Figure 1). Hamilton Lake is located on Fish Creek, a tributary of the St. Joseph, and subsequently, Maumee Rivers.

Lake Characteristics

Hamilton Lake surface area is reported on a 1956 DNR lake map as 802 acres (325 ha). Harza's computation, based on 1976 aerial photographs indicate a lake surface area of 739 acres (299 ha). The difference involves littoral wetlands that were connected to the lake in 1956, and have since been filled or isolated from the lake. Figure 2 shows the lake and its bottom contours. The maximum depth of the lake is about 70 feet (21 m); average depth is about 21 feet (6 m). Lake volume, as computed by Harza, is 15,852 acre-feet (19.5 million m^3).

Although it is a natural lake, the lake level has been stabilized at El. 898.6 ft msl by the construction of control structures at the outlets. Two dams were installed by the DNR. The southern dam has removable stop logs, allowing for the control of lake levels.

Hamilton Lake is heavily developed. Approximately 80% of the shoreline is developed with seasonal and year-round homes. Boating, fishing, water skiing, and swimming are popular forms of recreation.

Watershed Characteristics

Figure 3 is a map of the Hamilton Lake watershed, and shows the nine subbasins draining into the lake. These nine subbasins are the elements studied in the analysis of Hamilton Lake's watershed.

The total watershed area is 9,681 acres (3,918 ha). The watershed drains into Hamilton Lake largely through three main inlets from the west, east, and northeast. Black Creek is by far the largest tributary to the lake, consisting of subbasins 6, 7, 8, and 9. Black Creek drains about 5,600 acres (2,266 ha), or 58% of the total watershed.

Hydrologic data for this study come from the US Geological Survey's annual water reports and National Weather Service published records. There is a stream gaging station on Fish

Creek (Sta. 04177720, Fish Creek at Hamilton, IN) about 0.5 mile (0.8 km) downstream from the Hamilton Lake outlet. There are nearly 20 years of good records for this station. Average annual runoff at this station is 11.66 inches (29.6 cm) per year. Precipitation, as recorded in Angola, IN, by the National Weather Service, is 35.47 inches (90.1 cm) per year.

The land use maps were digitized from 1976 aerial photographs supplied by the USDA Agricultural Stabilization and Conservation Service in Angola. During the field surveys, the preliminary lands use maps were verified by ground truthing the watershed. Land use in the watershed, by subbasin, is tallied in Table 1. Residential development is largely limited to the shoreline. Figure 4 is a map of land use in the watershed. Figure 5 and Table 2 indicate the percentage of land being used for the land use categories. Grasslands, either in the form of Conservation Reserve "set aside" lands, hayfields, or idle lands are the most common land use, followed by lands used to grow row crops.

Soils and Sources of Sediment

The watershed is primarily composed of Glynwood-Morley-Blount soils series, described as deep, nearly level to moderately sloping, well drained to very poorly drained, silty soils on till plains (SCS 1981).

The recently published Nonpoint Source Assessment Report (IDEM 1989) estimated the land resource area that includes the study area to be eroding at an average rate of 4.9 T/ac/yr (10.1 mt/ha/yr). Figure 6 is a map showing soils considered by the Soil Conservation Service to be highly erodible. Highly erodible lands (HEL), particularly those actively farmed for production of row crops, can be a significant source of sediment to Hamilton Lake. About 61 % of the lake's total watershed is considered to be highly erodible. Subbasin 9 has the least percentage of HEL, with 38% of its subbasin being HEL; subbasin 1 has the greatest proportion, with 88%. Black Creek's drainage area is composed of subbasins 6,7,8, and 9 and contains about 56% of the highly erodible soils in the total watershed.

Table 3 tallies subbasin areas that are classified as highly erodible, and the acreage of those soils used for row crop production during 1989. Row crop production in the county is primarily corn or soybeans. The percentage of each subbasin's HEL used for row crops ranges from less than one percent in subbasin 1 to nearly one-third in subbasins 7 and 8. Watershed-wide, about 15% of the HEL are used for row crop production. A relatively high fraction (75%) of Black Creek drainage area's HEL is used for row crop production.

Large areas of the watershed have been set aside under the federal Conservation Reserve Program (CRP); these areas are shown in Figure 7. Large areas of the basin's HEL have been removed from row crop production under the CRP. Highly erodible land set aside under CRP ranges from none (subbasin 2) to 21% (subbasin 5) of the HEL in each subbasin; the watershed average is 15% (Table 3).

Another potential source of sediment to Hamilton Lake is the sand and gravel mining operation on the west side of the lake. Our planimetry indicates that in 1989 about one acre was being mined in subbasin 3, and 20 acres in subbasin 2. Field inspections were somewhat limited because of private ownership, but the mine does not appear to be a significant source of sediment to the lake. The presence of settling ponds and buffer lands around the mine and the absence of sediment in adjacent streams indicate the mine is not contributing significant sediments to the lake.

Many lake association members are concerned about the contribution of sediment and contaminants to the lake from an abandoned landfill in the watershed. The landfill, known as the Apollo Landfill, is located off county road 450 south, in Section 13, T 36 N, R 14 E. It was inspected in April, 1989 by the Steuben County Soil and Water Conservation District and in July, 1989 by the project staff. Most of the landfill is unvegetated, because of very poor site reclamation. Gully erosion is occurring on the sideslopes, transporting sediment off the site. The Soil and Water District's report includes recommendations for erosion control, and they should be implemented as soon as possible (Steuben County Soil and Water Conservation District 1989). The Apollo Landfill is rather distant from the lake, but sediment is being transported from the site into neighboring streams, and it is only a matter of time before these sediments reach Hamilton Lake.

Table 1					
LAND USE IN THE HAMILTON LAKE WATERSHED					
Subbasin	Urban (ac)	Wetlands (ac)	Row Crops (ac)	Grass (ac)	Forests (ac)
1	206.4	12.8	0.8	179.0	63.8
2	272.0	44.8	219.8	241.3	176.5
3	0	7.2	129.5	443.5	212.4
4	14.1	86.6	141.7	33.2	138.5
5	39.9	158.6	77.1	344.7	47.7
6	58.4	144.5	349.3	469.4	154.7
7	0	116.9	341.1	434.5	104.4
8	0	270.2	536.8	762.5	178.9
9	0	158.6	468.3	619.8	392.7
TOTAL	590.8	1060.2	2264.4	3527.9	1469.6

Table 2					
LAND USE PERCENTAGES IN THE HAMILTON LAKE WATERSHED					
Subbasin	Urban (%)	Wetlands (%)	Row Crops (%)	Grass (%)	Forests (%)
1	44	3	0	39	14
2	28	5	23	25	18
3	0	8	15	52	25
4	3	21	34	8	33
5	6	24	12	52	7
6	5	12	30	40	13
7	0	12	34	44	10
8	0	15	31	44	10
9	0	9	28	37	23
TOTAL	7	12	25	39	16

Table 3					
WATERSHED HIGHLY ERODIBLE LANDS (HEL), CRP LANDS, AND ROW CROP LANDS					
Subbasin	HEL (ac)	HEL set aside as CRP (ac)	HEL set aside as CRP (%)	HEL as Row Crop (ac)	HEL as Row Crop (%)
1	405	49	12	0.8	0.2
2	542	0	0	105	19
3	650	104	16	49	8
4	294	45	15	26	9
5	531	113	21	66	12
6	744	182	9	70	9
7	648	90	14	201	31
8	1018	136	13	325	32
9	635	81	13	156	25
TOTAL	5467	801	15	998	18

AQUATIC RESOURCES

Methods

Water, sediment, and plankton sampling was performed on August 1, 1989. Harza biologists collected plankton samples using an 80-micrometer mesh Student's plankton net. The plankton samples were preserved in the field with Lugol's solution. Two algal tows were done at the same location sampled for water quality testing, one from a depth of five feet (1.5 m) to the surface, the other from the thermocline (16 ft, or 4.9 m, depth) to the surface. Plankton were counted using a Sedgewick-Rafter cell and identified using a key published in APHA _et al_. (1985).

Water samples were also collected on August 1, 1989, on a hot, sunny day, between the hours of 11 am and 3 pm. Samples were taken at or near the deepest part of the lake and near the mouth of the three main tributaries (locations are shown on Figure 8). A sediment sample was taken approximately 100 yards from the mouth of Black Creek by compositing a number of grab samples. The Lake Association also collected a water sample at the mouth of Black Creek following a rain storm on July 27, 1989.

Lake water samples were collected using a Kemmerer bottle. The thermocline was first determined using a dissolved oxygen meter equipped with a temperature sensor (manufactured by Yellow Springs, Inc., Yellow Springs, Ohio). After the depth of the thermocline was determined, the Kemmerer bottle was used to collect a composite sample of equal portions from the epilimnion, the metalimnion, and the hypoliminion. Alkalinity was measured by titration to a colorimetric endpoint. Secchi disk visibility was measured in the field using a standard eight-inch black and white disk.

Water was sampled and tested according to _Standard Methods_ (APHA _et al_. 1985). Dissolved oxygen (DO), conductivity, alkalinity, and temperature were measured in the field. Other parameters were measured in the laboratory from samples collected and preserved in the field according to _Standard Methods_. Samples were kept on ice from the moment of collection until they reached the laboratory on the day after collection. Quality assurance procedures included the calibration of all field meters prior to their use according to manufacturer's instructions, and collection of separate lake epilimnetic and hypolimnetic samples as well as a composite of these (rather than duplicate samples). The contract laboratory was National Environmental Testing, Midwest of Streamwood, Illinois; this laboratory is approved by all major governmental agencies that certify labs, and has a long-standing record of quality service for Harza.

Fisheries

The Department of Natural Resources (DNR) Division of Fish and Wildlife Fisheries Section first surveyed the fish population of Hamilton Lake in 1977 (DNR 1977). The DNR caught 18 species of fish; bluegill (Lepomis macrochirus) dominated their catch, comprising 48% of the sample. Other fishes captured, in order of decreasing abundance, included redear sunfish (Lepomis microlophus), warmouth (L. gulosus), yellow perch (Perca flavescens), largemouth bass (Micropterus salmoides), and black crappie (Pomoxis nigromaculatus). Based on the 1977 survey, the DNR considered the Hamilton Lake fishery satisfactory.

In 1985, the DNR again surveyed the lake's fish population and published a fish management report for the lake (DNR 1985). The 1985 survey captured 24 species of fish; bluegill was still the most common fish, comprising 38% of the catch. Other common fishes captured included, in decreasing order of abundance, yellow perch, black crappie, gizzard shad (Dorosoma cepedianum), and largemouth bass. By weight, gizzard shad comprised most of the catch (27%), followed by northern pike (Esox lucius) at 12% and largemouth bass at 10%. The DNR reported that the bluegill population was stunted. However, the percentage of bluegill predators (largemouth bass and northern pike) of harvestable size was excellent.

The most significant change in the fish population between 1977 and 1985 was the increase in numbers and biomass of gizzard shad in the lake. The increases in gizzard shad population could be tied to the general eutrophication in the lake because of the gizzard shad's filter feeding habits and their greater tolerance for poorer water quality conditions.

The DNR is now managing Hamilton Lake for walleye (Stizostedion vitreum vitreum). According to the Lake Association, walleye were first stocked in the lake in 1988.

Macrophytes and Phytoplankton

The DNR's 1977 report contained a list of aquatic macrophytes found in Hamilton Lake. The list was repeated in the 1985 report and is shown below (Table 4). Note that Richardson's pondweed is currently on the State's List of Endangered Plants. Harza's field inspections verified most species in Table 4, including Richardson's pondweed (found at the head of the lake), as well as wild celery (Vallisneria americana) and willows (Salix sp.) in the lake or riparian areas.

The Lake Association has relied on herbicide applications to control aquatic weeds over the years. In 1988, 119.5 acres (48 ha) of the lake surface were treated by a professional weed control service at a cost of $18,163 (see Table 5). The Lake Association's regular control program involves a thorough spraying in the springtime and a secondary spraying in mid-summer in problem areas.

In 1973, phytoplankton and chlorophyll a were surveyed during May, August, and October (Table 6). On August 1, 1989 Harza collected and identified plankton in Hamilton Lake (Table 7). In the 1989 samples, blue-green algae (Cyanophyta) constituted 94% of the plankton in the top five feet (1.5 m) of the water column and 82% of all plankton in the top sixteen feet (4.9 m) of water. This dominance by blue-greens of late summer algal communities is typical for Indiana lakes, and is one indicator of trophic state used by the IDEM.

Water and Sediment Quality

Results of the 1989 water quality testing are given in Tables 8 and 9. Appendix A includes copies of the analytical reports from the laboratory. As Table 8 indicates, the lake was clearly thermally stratified during the sampling. The top 10 feet (3 m) had abundant oxygen concentrations and temperatures near 75 degrees F (24 C). Below the ten-foot depth, dissolved oxygen rapidly declined to nearly undetectable limits, and temperature dropped to about 46 degrees (8 C).

In general terms, Hamilton Lake water quality is moderately alkaline and fertile. Water clarity, in terms of secchi disk visibility was 3.4 feet (1 m). This is rather low clarity, and was largely due to the high numbers of phytoplankton in the water on the day of sampling. Plankton numbers were high, not only because of the nutrient concentrations, but also the season of sampling.

For comparison to the data presented in Tables 8 and 9, the State's water quality standards applicable to Hamilton Lake are given in Table 10. Hamilton Lake likely stays within the standards during the recreational season; however, as evidenced by the Black Creek samples taken after a rain storm on July 27, 1989, the lake may not meet the bacteriological standards after storms because of watershed sources of coliform bacteria. Hamilton Lake, like all lakes and reservoirs in the State, is legally designated for recreational use (including whole-body contact recreation) and support of warm water aquatic life.

On August 1, 1989, mean water column total phosphorus was 0.05 mg/L, of which about 20% was ortho-phosphate, a readily bioassimilatable form of phosphorus. For comparison, the US EPA National Eutrophication Survey (USEPA 1974) considered total phosphorus concentrations above 0.02 mg/L to be from eutrophic lakes; the US EPA considered mesotrophic lakes (moderately productive) lakes to have 0.01 to 0.02 mg P/L, and oligotrophic lakes (low productivity) to have total phosphorus concentrations less than 0.01 mg/L. Hence, Hamilton Lake has rather high phosphorus concentrations, and would be considered by the US EPA to be eutrophic. The nitrogen to phosphorus ratio (N:P), an indicator of which of these two nutrients limits productivity, was 35. An N:P in this range indicates a phosphorus-limited ecosystem (Wetzel 1983). Most fresh waters are phosphorus limited.

Hypolimnetic (deep) waters of Hamilton Lake were much richer in nutrients than the epilimnion (surface waters). This phenomenon is largely due to the absence of oxygen from bottom waters and commonly occurs in Indiana lakes. Hypolimnetic total phosphorus was 0.10 mg/L, compared to 0.03 mg/L in the epilimnion. Hypolimnetic total nitrogen was 1.11 mg/L; epilimnetic total nitrogen was 0.69 mg/L. A large fraction of these higher concentrations of nutrients in the hypolimnion represent nutrients that are "recycled" on an annual basis; as summertime oxygen levels in the bottom waters approach zero, the sediment releases both phosphorus and nitrogen to the water column.

Fecal coliform and streptococcus bacteria are indicators of sewage contamination. These bacteria were very low in the composite lake sample, but were at higher concentrations in incoming streams. The fecal coliform to fecal streptococcus ratio (FC:FS) is a general indicator of the source of pollution. FC:FS above 4.1 is considered to be indicative of pollution derived from human excrement, whereas FC:FS less than 0.7 suggests pollution due to non-human sources like livestock, wildlife or pets (APHA et al. 1985). The July 27 Black Creek sample taken after a rainstorm had a FC:FS of 59, and suggests that the runoff brought human sanitary wastes into Hamilton Lake.

Water quality data from previous studies have been supplied to Harza by the Department of Environmental Management (IDEM). Table 11 includes some of these data. The samplings were done in 1973 and 1986. In general, significantly lower concentrations of nitrogen and phosphorus nutrients were detected in 1986 than in 1973. The improvements in water quality between 1973 and 1986 are, among other things, attributable to the installation of a sanitary sewer system around the lake.

Sediment quality data from this study are given in Table 12. A composite sediment sample was taken approximately 75 to 150 yards due west of Black Creek's mouth. Total phosphorus concentration is typical for a eutrophic lake, and, typical for Midwestern lakes in agricultural watersheds. The level of total phosphorus found in the sample is considered to be "non-polluted," according to the US Environmental Protection Agency's classification of Great Lakes harbor sediments (USEPA 1977). The EP (Extraction Procedure) Toxicity results indicate that the sediment sample is not considered hazardous, based upon heavy metals or pesticide EP Toxicity. However, the IDEM found trace levels of contaminants (pesticides, PCBs, metals) in fish flesh and sediments in 1986. The concentrations of contaminants that IDEM found in fish are well below the levels specified by the US Food and Drug Administration as potentially hazardous to human health.

Other Resources

The DNR Division of Nature Preserves was contacted during this study. They checked the Indiana Natural Heritage Program's database and sent us a letter regarding their concerns. In summary, the Division had the following comments:

1. The state endangered plant Richardson's pondweed was found in the lake;

2. A "county-notable" wetland on the north side of the lake contains a small floating sphagnum mat;

3. Fish Creek contains some of the best remaining fresh-water mussel fauna in the region and may harbor federally-listed endangered mussels. The Division is concerned about water quality degradation;

4. Douglas Woods (in De Kalb County) is a notable natural area;

5. An osprey was sighted near Ball Lake in 1986.

Table 4

AQUATIC PLANTS IN HAMILTON LAKE
(Source: DNR Fisheries Division Files, dated 1977)

Common Name	Scientific Name
Watermilfoil	*Myriophyllum* sp.
Richardson's pondweed	*Potamogeton richardsonii*
Curlyleaf pondweed	*P. crispus*
Coontail	*Ceratophyllum* sp.
Star duckweed	*Lemna trisulca*
Chara	*Chara* sp.
Spatterdock	*Nuphar advena*
White waterlily	*Nymphaea tuberosa*
Common cattail	*Typha latifolia*
Soft rush	*Juncareae* sp.
Arrowhead	*Sagittaria* sp.
Pickerelweed	*Pontederia cordata*

Table 5

HAMILTON LAKE 1988 HERBICIDE APPLICATIONS
(Source: Aquatics Unlimited, Inc.)

Chemical	Total Amount Used
Copper sulfate	30 pounds
Diquat	47 gallons
Aquathol K	187 gallons
2,4-D	2,600 pounds
Komeen	202.5 gallons
Cide-Kick II (activator)	120 gallons
Poly-control (sinking agent)	35 gallons
Rodeo	2.5 gallons

Table 6

PHYTOPLANKTON AND CHLOROPHYLL a IN 1973 IN HAMILTON LAKE
(Source: IDEM Files)

	5/3/73	8/4/73	10/13/73
	(Algal Units per ml)		
<u>Aphanizomenon</u> <u>sp.</u>	195		107
<u>Melosira</u> <u>sp.</u>	114		
Flagellates	114		
Coccoid cells	81	890	
<u>Asterionella</u> <u>sp.</u>	32		
Other genera	48	612	305
<u>Oscillatoria</u> <u>sp.</u>		1,187	
<u>Merismopedia</u> <u>sp.</u>		244	
<u>Microcystis</u> <u>sp.</u>		244	137
<u>Fragilaria</u> <u>sp.</u>		192	198
<u>Lynbya</u> <u>sp.</u>			244
<u>Chroococcus</u> <u>sp.</u>			91
TOTAL	584	3369	1082
Mean Chlorophyll a	2.6 ug/L	8.5 ug/L	5.1 ug/L

Table 7

PLANKTON AND CHLOROPHYLL a IN HAMILTON LAKE, AUGUST 1, 1989

Plankton	Concentration (units per mL) 16 ft to Surface	5 ft to Surface
CHLOROPHYTA		
Pediastrum	1	0
PYRRHOPHYTA		
Ceratium	0	0
BACILLARIOPHYTA		
Melosira	371	16
Fragilaria	1	0
CYANOPHYTA		
Microcystis	164	22
Coelosphaerium maegelianum	731	194
Anabaena spiroides	196	22
Anabaena subcylindrica	307	17
Oscillatoria sp.	315	12
Anacystis sp.	32	5
	2,119	289
ZOOPLANKTON		
Copepod nauplii		
Daphnia retrocurva		
Bosmina longirostirs		
Tropocyclops		
Cyclops copepodites		
Diaptomus oregonensis		
Diaptomus copepodites		
Keratella cochlearis		
Keratella crassa		
Asplanchna sp.		
Polyarthra vulgaris		
Mesocyclops edax		

Note: Ceratium and all zooplankton listed were identified as part of the plankton, but the computation of lake plankton concentrations estimated these species at less than one per mL.

Table 8

WATER QUALITY ANALYSES PERFORMED IN THE FIELD

Hamilton Lake
August 1, 1989

Depth (m)	Temp (deg C)	Dissolved Oxygen (mg/L)	Total Alkalinity (mg/L CaCO3)	Conductivity (umhos/cm)
0.3	25.0	7.8	140	323
1.0	24.5	7.9		322
2.0	24.0	7.8		318
3.0	24.0	7.7		318
3.5	23.5	3.9		312
4.0	23.0	2.5		
4.5	22.5	1.5		
5.0	21.0	0.3		305
5.5	18.0	0.2		275
6.0	17.0	0.2		
6.5	15.0	0.1		274
7.0	14.0	0.1		
8.0	12.5	0.1		263
9.0	11.0	0.15		256
10.0	10.0	0.1		255
11.0	9.5	0.1		255
12.0	9.0	0.1		
13.0	9.0	0.1		
14.0	8.5	0.1		
15.0	8.5	0.1		
16.0	8.0	0.05		
17.0	8.0	0.1		
18.0	8.0	0.1		
19.0	8.0	0.05		
20.0	8.0	0.05		

Table 9

RESULTS OF LABORATORY ANALYSES

LOCATION	SAMPLE TYPE	DATE d/m/y	AMMONIA NITROGEN (mg-N/L)	KJELDAHL NITROGEN (mg-N/L)	NITRATE NITROGEN (mg-N/L)	NITRITE NITROGEN (mg-N/L)	TOTAL * NITROGEN (mg-N/L)	DISSOLVED ORTHO PHOSPHORUS (mg/L)	TOTAL PHOSPHORUS (mg/L)	N:P (atoms)
Hamilton Lake	Grab (1.6m)	1/8/89	0.24	0.45	<0.01		0.69		0.03	51
Hamilton Lake	Composite	1/8/89	0.29	0.50	<0.01	<0.01	0.79	0.01	0.05	35
Hamilton Lake	Grab (5m)	1/8/89	0.33	0.78	<0.01	<0.01	1.11		0.10	25
Jackson Judson Creek	Grab	1/8/89	0.17	0.25	0.55	0.05	1.02	0.07	0.07	32
Unnamed Tributary	Grab	1/8/89	0.36	0.54	<0.01	<0.01	0.9	0.11	0.13	15
Black Creek	Grab	1/8/89	0.38	0.50	0.38	0.02	1.28	0.04	0.07	40
Black Creek	Grab (storm)	27/7/89	0.28		1.24	0.05	1.57	0.05	0.04	87

LOCATION	SAMPLE TYPE	DATE d/m/y	5-DAY BIOCHEMICAL OXYGEN DEMAND (mg/L)	TOTAL SUSPENDED SOLIDS (mg/L)	FECAL COLIFORMS (#/100mL)	FECAL STREPTOCOCCUS (#/100mL)	FC:FS	Chlorophyll a (mg/L)	Pheophytin (mg/L)
Hamilton Lake	Grab (1.6m)	1/8/89		5					
Hamilton Lake	Composite	1/8/89		2	16	0	ERR	0.011	0.015
Hamilton Lake	Grab (5m)	1/8/89		6					
Jackson Judson Creek	Grab	1/8/89		8	110	127	0.9		
Unnamed Tributary	Grab	1/8/89		19					
Black Creek	Grab	1/8/89		6					
Black Creek	Grab (storm)	27/7/89	3	12	5300	90	59		

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* Excludes diatomic nitrogen

Table 10

WATER QUALITY STANDARDS APPLICABLE TO HAMILTON LAKE

Parameter	Standard
Dissolved Oxygen	Daily Average of 5.0 mg/L Minimum of 4.0 mg/L
pH	6.0 - 9.0
Fecal Coliform Bacteria	Less than 400/100 mL or Less than 200/100 mL per 5 samples in 4-week period

Source: Indiana Administrative Code, Title 330, Article 1. Water Quality Standards.

Table 11

PAST WATER QUALITY DATA ON HAMILTON LAKE
(Source: IDEM files)

LOCATION	SAMPLE DEPTH (ft)	DATE d/m/y	AMMONIA NITROGEN (mg-N/L)	KJELDAHL NITROGEN (mg-N/L)	NITRITE + NITRATE NITROGEN (mg-N/L)	TOTAL NITROGEN (mg-N/L)	ORTHO PHOSPHORUS (mg/L)	TOTAL PHOSPHORUS (mg/L)	N:P	PHYTO-PLANKTON (units/mL)	CHLOROPHYLL a (mg/L)	SECCHI DISK (ft)
Hamilton Lake	Water column average	3/5/73	0.154	0.783	0.569	1.352	0.017	0.031	97	584	0.0025	9.3
Hamilton Lake	Water column average	4/8/73	0.482	1.508	0.238	1.747	0.088	0.128	30	3369	0.0447	4.5
Hamilton Lake	Water column average	13/10/73	1.000	2.108	0.046	2.154	0.121	0.170	28	1082	0.0051	7.7
Hamilton Lake near outlet	Surface	31/7/86	<0.1	0.8	<0.1	0.8		<0.03				4.0
Hamilton Lake near outlet	30	31/7/86	<0.1	0.6	0.4	1.0		<0.3				
Hamilton Lake north end	Surface	31/7/86	<0.1	0.9	<0.1	0.9		<0.03				4.3
Hamilton Lake north end	25	31/7/86	<0.1	0.6	<0.1	0.6		<0.03				

Table 12

SEDIMENT QUALITY

Parameter	Value	
Moisture	61%	
Total Phosphorus	306 ug/g	
Particle Sizes		
#60 sieve (0.25 mm)	12.2%	
#80 sieve (0.2 mm)	6.6%	
#100 sieve (0.15 mm)	2.5%	
#200 sieve (0.075 mm)	8.6%	
#230 sieve (0.06 mm)	1.4%	
Pan (<0.06 mm)	68.7%	
EP Toxicity		Maximum Contaminant Level (mg/L)
Arsenic	0.004 mg/L	5.0
Barium	0.672 mg/L	100.0
Cadmium	<0.005 mg/L	1.0
Chromium	0.002 mg/L	5.0
Lead	<0.04 mg/L	5.0
Mercury	<0.0001 mg/L	0.2
Selenium	<0.001 mg/L	1.0
Silver	<0.005 mg/L	5.0
Endrin	<0.1 ug/L	0.02
Lindane	<0.05 ug/L	0.4
Methoxychlor	<0.5 ug/L	10.0
Toxaphene	<0.05 ug/L	0.5
2,4-D	<2.0 ug/L	10.0
2,4,5-TP Silvex	<2.0 ug/L	1.0

All data on a dry weight basis.

Maximum contaminant level is the level which the EP Toxicity concentration must exceed to be considered hazardous.

PROBLEM IDENTIFICATION

Lake Eutrophication Index

A Lake Eutrophication Index (LEI) based upon the Indiana Department of Environmental Management's system (IDEM, 1986) was updated for Hamilton Lake as part of this study. A LEI is a numerical rating of a lake's trophic or productivity status; the higher the index, the greater the lake's productivity. The IDEM computed a LEI in the mid-1970's and again in the mid-1980's; IDEM computed the LEI on both occasions to be 31. The updated LEI is 28, a minor improvement. Table 13 details our computation of the LEI, based upon the IDEM system. Secchi disk visibility (SD, in feet) was substituted for the LEI variable for light transmittance (L) by the use of equations 1 and 2:

$$L_{1\%} = 2.5 * SD \qquad \text{(Eq. 1)}$$

$$\log L_{3'} = 3/-1.25/SD \qquad \text{(Eq. 2)}$$

where, $L_{1\%}$ is the depth (feet) at which light transmittance is 1% of the incident light, and $L_{3'}$ is the light transmittance at the three-foot depth. The substitution of secchi disk visibility was made per discussions with "T by 2000" lake enhancement staff. Equation 2 assumes that light transmission is inversely related to depth in a semi-logarithmic manner.

The reduction from 31 to 28 eutrophy points does not change Hamilton Lake's classification as a Class 2 lake. Class 2 lakes are of intermediate quality. Class 2 lakes are productive, moving slowly towards senescence, are impacted by anthropogenic activities, and may have problems with aquatic weeds and plankton. The majority of Indiana's lakes are Class 2 lakes.

For management purposes, the IDEM considers Hamilton Lake to be a Group VI C lake (IDEM 1986). In general, lakes of this type do not have water quality problems severe enough to warrant drastic restoration measures, such as lake dredging. Rather, the IDEM may recommend selected restoration measures, namely, nutrient inactivation, selective water discharge, weed harvesting, or algicides. The management priority, however, which will have the greatest benefits is generally the limitation of nutrient inputs to the lake.

Nonpoint Source Phosphorus Modeling

From this and previous studies, Hamilton Lake can be classified as eutrophic. Phosphorus is the limiting nutrient, and the National Eutrophication Survey performed by the US Environmental Protection Agency estimated that about 90% of the phosphorus entered from nonpoint watershed sources (the remainder came from the lakeside septic tanks in service at that time and from atmospheric deposition).

Hamilton Lake was included in the IDEM's assessment of state waters impaired by nonpoint source pollution (IDEM 1989). Although this assessment was subjective, the information was provided as a dynamic planning document, to be routinely updated as more rigorous data become available. The IDEM report listed Hamilton Lake as being impaired to support aquatic life. The probable source of this impairment was stated as non-irrigated crop production in the watershed. The probable cause was siltation and nutrient loading.

The present "T by 2000" feasibility study reestimated lake phosphorus (P) loadings and mean annual water column phosphorus concentrations using an empirical model developed by Reckhow (Reckhow and Chapra, 1983; Reckhow and Simpson, 1980). Reckhow's model was selected for use because it quantifies uncertainty and was developed using data from many lakes in the Midwest. Computation of uncertainty is important here because of the limited field data available. The model's computations were done using spreadsheet software.

Appendix B includes the details on the nonpoint source computations. Briefly, Reckhow's model is based on 47 temperate north lakes included in the US EPA's National Eutrophication Survey. The model expresses phosphorus concentration (P, in mg/L) as a function of phosphorus loading (L, in g/m^2-yr), areal water loading (q_s, in m/yr), and apparent phosphorus settling velocity (v_s, in m/yr) in the form of equation 3:

$$P = \frac{L}{v_s + q_s} \qquad \text{(Eq. 3)}$$

By least squares regession of the 47 lakes data, Reckhow fitted apparent phosphorus settling velocity as a weak function of areal water loading:

$$P = \frac{L}{11.6 + 1.2q_s} \qquad \text{(Eq. 4)}$$

Using equation 4 and Reckhow's procedure, phosphorus loadings to a lake, and mean annual lake phosphorus concentrations can be estimated.

Loadings are estimated based upon land use areas and phosphorus export coefficients. Phosphorus export coefficients for various land use types were carefully selected for use in the model from a compilation and comparison by Reckhow et al. (1980). Nonpoint sources included in the model were forest lands, row crop lands, highly erodible row crop lands, grasslands, urban areas, wetlands, and the atmosphere. Export coefficients were selected for these land use types according to climate, location, soil type, and vegetative cover. Since phosphorus is generally transported sorbed onto soil particles, higher export coefficients were used for row crops on highly erodible soils than non-highly erodible soils. No point sources of phosphorus were found in the watershed or included in the model.

For the sake of practicality, high, most likely, and low export coefficients were selected, allowing computation of high, most likely, and low phosphorus loadings and mean lake water column concentrations. The high and low estimates represent the computation's uncertainty, since actual phosphorus export coefficients were not measured in the Hamilton Lake watershed. This uncertainty represents error that is in addition to Reckhow's empirical model error and must be included in the computation of total uncertainty. In other words, the range between the high and low estimates reflects the uncertainty inherent in extrapolating the information from Reckhow's compilation of export coefficients to the study area.

Reckhow's phosphorus model predicts a mean annual water column average total phosphorus concentration of 0.044 mg/L. The 55% confidence limits bounding this estimate are 0.022 mg/L and 0.089 mg/L. Given the mean water column total phosphorus concentration of 0.05 mg/L measured in August, 1989, the 0.044 mg/L estimate is reasonable. Reckhow considers this level of phosphorus indicative of eutrophic lakes. Based upon this model, as well as the field water quality data, Hamilton Lake must be classified as eutrophic, and lacking the chemical and biotic characteristics desired by lake users. Admittedly, there are factors other than total phosphorus important in determining trophic status, but in systems like Hamilton Lake where phosphorus is the limiting nutrient, total phosphorus is the most important variable in predicting primary productivity in temperate lakes (Prairie et al. 1989).

The estimates of the phosphorus model were used to place Hamilton Lake on Vollenweider's phosphorus loading plot, Figure 9 (Vollenweider 1975). For comparison, a nearby lake, Sylvan Lake, is also included in Figure 9. The plot has three basic zones, and a lake's datum will fall within one of those zones: eutrophic, mesotrophic, or oligotrophic. The upper zone is eutrophic lakes; the bottom zone is oligotrophic lakes. Mesotrophy is indicated by a datum falling in the midregion of the plot.

Table 14 gives the phosphorus model's estimates of most likely mean annual phosphorus loadings to the lake from each subbasin's sources. Row crops that are being farmed on highly erodible soils represent the single largest source of phosphorus to Hamilton Lake and are about 45% of the total loading of about 2,300 kg/ha. Grassland, because of its abundance in the watershed, is the second largest source of phosphorus to the lake, about 25% of the total. Row crops on non-highly erodible soils are third, representing about 22% of the total. Other sources are essentially negligible.

Black Creek watershed (subbasins 6, 7, 8, and 9) contributes about two-thirds of the annual phosphorus loadings to the lake. This is a slightly disproportionate amount considering that Black Creek drains about 58% of the total watershed.

Table 14

"MOST LIKELY" MEAN ANNUAL PHOSPHORUS LOADINGS (mg/L) TO HAMILTON LAKE

Source	1	2	3	4	5	6	7	8	9	Total
Forest	3	7	9	6	2	6	4	7	16	59
Row Crop Land	0	46	33	47	5	113	57	86	127	513
Highly Erodible Row Crop Land	1	107	49	27	66	70	203	329	176	1,028
Grass Land	29	39	72	5	56	76	70	123	100	571
Urban Runoff	50	66	0	3	10	14	0	0	0	143
Wetlands	-1	-4	-5	-7	-13	-12	-9	-22	-13	-86
Mining	0	6	0	0	0	0	0	0	0	6
Shrubland	0	0	0	0	0	0	0	0	1	1
Atmosphere	0	60	0	0	0	0	0	0	0	60
Total	81	327	157	81	126	268	325	523	408	2,296

EVALUATION OF LAKE ENHANCEMENT ALTERNATIVES

Approach

The purpose of any engineering feasibility study is to identify, compare, and screen project alternatives and to select one or more alternatives for further study or design. Alternative methods for enhancing Hamilton Lake were evaluated using a three-level procedure, with the depth of study increasing as the list of alternatives narrowed to those most feasible. The evaluation system's three levels are:

Level 1. **Initial Identification** - A comprehensive list of reasonable lake enhancement methods was compiled.

Level 2. **General Screening** - Alternatives which were obviously not applicable to Hamilton Lake, had unacceptable environmental impacts, or unproven technology were eliminated from further consideration.

Level 3. **Feasibility Evaluation** - Alternative methods were evaluated for technical feasibility for enhancing Hamilton Lake. Those alternatives remaining for evaluation at this level of study were prioritized for implementation based on effectiveness and cost.

Level One - Identification

Hamilton Lake is a valuable resource for Steuben County. The uses of the lake are being impacted by the accelerated aging (or cultural eutrophication) of the lake. The obvious symptoms of this accelerated aging are the large beds of aquatic macrophytes, the summertime algae blooms, and the sediment plumes seen in the lake following storm runoff events. Less obvious symptoms include gradual decreases in lake depth and water clarity. Below, we describe various methods for remedying these lake problems.

A list of macrophyte control alternatives is presented in Table 15. Table 16 is a list of in-lake alternatives for reducing phosphorus concentrations in Hamilton Lake. Beside each listed alternative are comments reflecting the applicability to the specific problem at Hamilton Lake.

Agricultural land management schemes or BMPs (Best Management Practices) are very important lake management tools in rural watersheds. The objective of most BMPs is soil and water conservation; keeping soil in place, and slowing the runoff of rain water helps keep pollutants form entering water courses and downstream lakes. Examples of BMPs include contour farming, strip cropping, terracing, low till and no-till farming, grassed waterways, etc. BMPs should generally be selected on a field by field basis, at a level of detail beyond the scope of this particular watershed study. However, the important of good conservation and land management practices cannot be overemphasized. Technical and financial assistance to implement BMPs is available from the County Soil and Water Conservation District and watershed residents are strongly encouraged to seek out this assistance.

Level Two - Screening

The initial list of alternatives was screened, and only those determined to be suitable for implementation were carried forward to the feasibility evaluation stage. The criteria for this screening included obvious applicability and utility, unacceptable environmental or social impacts, legal constraints, and unproven technology.

The macrophyte control alternatives carried on to the feasibility level of study were mechanical harvesting, herbicides, and shading using dyes. Harvesting is the only weed control method that removes nutrients from the lake. These techniques are short-term control methods and must be combined with phosphorus control. Triploid (genetically sterile) grass carp (Ctenopharyngodon idella) should be considered should this alternative ever be permitted in Indiana. They are illegal at present. Other alternatives not carried forward for feasibility evaluation, and the reasons for their elimination, are given in Table 15.

Phosphorus control alternatives carried forward to the feasibility level of study include both in-lake control of phosphorus and source control. In-lake phosphorus control basically involves restriction of sediment-generated or recycled phosphorus. In-lake phosphorus control methods carried forward to the feasibility level of study include sediment phosphorus inactivation using aluminum salts, hypolimnetic aeration, and artificial circulation. In lakes with very high internal phosphorus loadings or highly contaminated sediments, sediment removal has been used to successfully restore the lake. A side benefit of sediment removal is deepening the lake, so fewer rooted macrophytes are able to grow. At Hamilton Lake, nonpoint sources are the greatest threat to the lake at present, and, given the high cost of sediment removal, it is not warranted. Sediment removal typically costs \$4 to \$6 per cubic yard.

Nonpoint source control of phosphorus inputs to the lake is generally linked with control of soil erosion and sedimentation through Best Management Practices (BMPs) and/or sediment traps. Phosphorus is generally transported in streams adsorbed to soil particles, so removal of the soil particles from the stream system frequently removes incoming phosphorus as well. Wetland creation (sediment traps) was also carried forward to the feasibility level of study. Streambank erosion is a minor source of sediment being carried into the lake; during the field reconnaissances, we did not view any severe bank erosion. Overbank runoff and localized scour around culverts and field tile outfalls does exist, but the areas of such disturbance is minor.

The US EPA, SCS, and other agencies have developed BMPs for watershed management and lake water quality protection. Many BMPs focus on runoff control, but have coincidental water quality benefits. An example control method already in place is the Conservation Reserve Program, where highly erodible soils are taken out of row crop production and set aside for ten years. Nutrient input to Hamilton Lake will undoubtedly be reduced because of the CRP set asides in the basin.

Level Three - Feasibility Evaluation

Weed Harvesting. Harvesting, or cutting and removing rooted aquatic plants, has been practiced in Midwestern lakes for many years. Although harvesting is only effective in the short-term, it has some lake restorative value because the plants are removed from the lake. Because they are removed from the lake, the plants do not decompose in the water, consume dissolved oxygen, and release their nutrients to the water column. Disposal of the weeds is not usually a problem; the vegetation makes excellent mulch and fertilizer for gardens. The weeds should be utilized at locations away from the lakeshore and water courses. Harvesters should cut the vegetation at least five feet deep. Harvesting can be done in water that is at least deep enough to float the harvester, say 18 inches.

Macrophyte mowers are available but they do not remove the vegetation from the lake, and, although they are considerably less expensive than harvesters, mowers are not recommended.

Weed harvesters are available from specialty manufacturers. Alternatively, contract harvesting can be periodically performed. Experience indicates that during the first year of harvesting, spring, mid-summer, and late summer harvesting should be done. After this first year's program, succeeding years' weed growth is generally less and a single harvesting is sufficient. Assuming Hamilton Lake follows this general trend, first year harvesting costs will be approximately $135,000, and costs in succeeding years will be about $45,000.

Adverse ecological effects are few. The weeds will return and harvesting will need to be repeated. Harvesting is generally increasingly effective in later years. With fewer macrophytes, phytoplankton concentrations may increase, and water clarity may decrease. Macrophytes should not be harvested from certain locations, such as the head of the lake and mouths of tributaries for fish habitat and filtration of the incoming water.

Richardson's pondweed is a state endangered plant that resides in the head of the lake despite the annual herbicide applications. When the Lake Association implements a harvesting program, the DNR's Division of Fish and Wildlife (or a qualified contractor) should be invited to resurvey the head of the lake to determine the distribution of the plant and segregate that portion of the lake from the harvesting area.

Access to the lakefront for offloading harvested weeds is somewhat limited at Hamilton Lake. Temporary access however can be created at several points around the lake at minimal costs.

<u>Herbicides</u> <u>and</u> <u>Shading.</u> Controlling macrophytes using herbicides is effective, but herbicide use is not lake restoration (i. e., does not remove nutrients). Likewise, dyes that decrease light penetration into the water also control plants, but cannot be considered a lake restoration method. Neither of these techniques addresses the causes of weed growth, nor do they remove weed organic matter or nutrients from the lake. These methods cause plants to die, to decompose on the lake bottom, and eventually to release their nutrients back to the water column.

Some herbicides are specific to certain plants. Application needs to be done according to the manufacturer's instructions, and in Indiana, by licensed applicators. The Hamilton Lake Association has had a successful weed control program in place for several years, but it has been costly, and, the Association is now seeking to implement a long-term control strategy. Weed control by herbicides and/or dyes may continue as part of that strategy, especially to control weeds in localized areas like beaches and boat docks.

<u>Phosphorus</u> <u>Inactivation.</u> Phosphorus precipitation and inactivation are well demonstrated lake enhancement techniques. The lake phosphorus content is reduced by precipitating phosphorus from the water column and retarding phosphorus release from lake sediments. Phosphorus (P) is removed through formation of an insoluble precipitate, by sorption onto the surface of flocs or polymers, and by occlusion and sedimentation of P-containing particles in these flocs (Cooke and Kennedy, 1981). Aluminum and certain other metals (iron and calcium for instance) form strong bonds with phosphate, and, by adding certain of these salts to the lake, P is tightly bound to aluminum. This process is dependent on water pH and alkalinity. So, by chemically

binding the nutrient phosphorus irreversibly to lake sediments, internal loading is greatly reduced.

Internal loading at Hamilton Lake was not specifically measured. However, the sediments do release phosphorus to the hypolimnion during summer stratification. During sampling on August 2, 1989 hypolimnetic total phosphorus was 0.10 mg/L, compared to mean water column and epilimnetic concentrations of 0.05 and 0.03 mg/L, respectively. On August 2, the hypolimnetic volume was about 8,400 acre-feet, or slightly more that half of the lake volume. The hypolimnion contained only half the volume of water but approximately three-quarters of the total phosphorus in the lake. Hence, inactivation of sediment-released phosphorus would have significant benefits for the lake by improving water clarity.

Aluminum (Al) is the most common element for inactivating lake phosphorus. Power plant fly ash and certain clays can also be used. Al salts, generally alum or sodium aluminate, are applied in either liquid or solid form to the lake's hypolimnion, as the sediment is the source of the internal phosphorus. Table 17 gives initial estimates of alum requirements for Hamilton Lake. Actual implementation of an alum treatment would require several batch tests to refine the dose.

Table 17

ESTIMATED ALUM REQUIRED TO
INACTIVATE HAMILTON LAKE INTERNAL PHOSPHORUS

	Requirement	
Alum Type	(kg)	(tons)
$Al(SO_4)_3 \cdot 18\ H_2O$	3,370,000	1,500
$Al(SO_4)_3 \cdot 14\ H_2O$	3,000,000	1,400

Nearly every aluminum treatment has been successful in bringing about a reduction in lake phosphorus concentration and an improvement in trophic state. The problems that have been encountered have been caused by insufficient dose, lake mixing, or insufficient diversion of incoming nutrients (Cooke <u>et al</u>. 1986).

Bulk alum generally costs about $145/t FOB. Contractor's rates for alum application are $260 per ton, including materials, labor, overhead, and profit. Hence, phosphorus inactivation for Hamilton Lake will cost about $390,000.

There is some potential for adverse ecological effects with this method. Dissolved aluminum is toxic to aquatic biota at levels above about 50 ug/L (Cooke <u>et al</u>. 1986), but this level is strongly pH dependent. At increasing differences from a neutral pH (7.0), Al is increasingly soluble. Also, the hydrolysis reaction that occurs when alum is mixed with water lowers pH. Consequently, a lake's alkalinity (neutralization capacity) is an extremely important consideration in planning alum treatments, and, during alum applications, pH should be monitored. The above alum dose estimates were computed based upon an average of 100 mg $CaCO_3$/L total alkalinity and pH 7.55 in Hamilton Lake.

<u>Hypolimnetic Aeration.</u> Hypolimnetic aeration removes the anoxic characteristics of hypolimnia and their symptoms. One symptom of an anoxic hypolimnion is the dissolution of phosphorus from sediments. When oxygen is added to the bottom waters of the lake, the oxidation-reduction potential is raised, and the chemical nature of dissolved matter changes. Oxygenated hypolimnions do not solubilize phosphorus from the lake sediments. This lake restoration technique has three objectives:

- Oxygenating the hypolimnion without destratifying the lake
- Increasing the inhabitable volume of the lake and the invertebrate food supply of fishes
- Decreasing the internal loading of P by establishing oxic (oxygen rich) conditions at the sediment-water interface

There are many designs that have been used as hypolimnetic aerators, but all fall into one of three basic types: mechanical agitators that withdraw, oxygenate, and return hypolimnetic water; hypolimnetic injection of pure oxygen; and injection of air. The first type, mechanical agitation, is inefficient, both in terms of energy for operation and oxygen transfer, and is the least popular method.

Pure oxygen has been used in lake restoration, but is not yet used commonly. It is expected to be exploited more in the near future. It is commonly applied with high efficiencies in fish hatcheries (near 100% transfer efficiencies) and in the near future, in aerating hypolimnetic releases from impoundments (Harza, in press).

The most common hypolimnetic aeration system is a partial air-lift. Full air-lift systems bring hypolimnetic water to the surface and return it, after eliminating air bubbles and dissolving some air. Partial air-lift systems aerate hypolimnetic water at depth (Figure 10). Probably the most popular partial air-lift is marketed by Atlas Copco, Aquatec (Wilrijk, Belgium), as the "Limnox," but other systems are available.

One advantage of hypolimnetic aeration is that lake stratification is maintained (not the case for artificial circulation), and sedimented P is not resuspended and recirculated into the epilimnion. Theoretically, nitrogen supersaturation is possible with hypolimnetic aeration, but it has not been reported as a problem in the literature.

Both capital and operating costs for hypolimnetic aeration are high. Although insufficient data have been collected for sizing a system specific to Hamilton Lake, comparison to other lakes indicates that between 8 and 12 "Limnox" units will be required, and capital costs would be on the order of $2,300,000.

Artificial Circulation. Artificial circulation has been used by lake managers for three decades. It was initially used to prevent winterkill in lakes and now has become the most commonly used of all lake restoration measures in the U.S. Using technology similar to hypolimnetic aeration, artificial circulation destroys a lake's stratification, raises the temperature of the lake, oxidizes organic compounds in the water column more rapidly, and aerates the whole lake volume. Circulation also frequently increases lake turbidity, shifts dominance of the plankton community from blue-green algae to diatoms and green algae, and reduces overall abundance of algae.

Artificial circulation can be induced by injecting air into the hypolimnion through coarse or fine bubble diffusors, mixing with underwater fans, and other methods. However, air injection is by far the most common and least expensive (Cooke, et al. 1986). Water is upwelled through the action of rising bubbles, and the lake is destratified and mixed.

Unfortunately, artificial circulation is not always effective at reducing lake phosphorus concentrations because particulate phosphorus is resuspended and may become available to algae. Also, turbidity is sometimes increased. Supersaturation of nitrogen has been documented, but not to a level lethal to fishes (Cooke, et al. 1986).

Artificial circulation is mainly effective at controlling the water quality, lake thermal structure, and the composition and abundance of plankton. Macrophytes will only be affected by the decrease in light penetration because of the greater turbidity, if total phosphorus is decreased (the literature is conflicting on this point).

Implementation costs are similar to hypolimnetic aeration, and, because of the frequently mixed results of artificial circulation, it is not carried forward to the third level of study.

Wetland Creation. Wetlands, whether natural or created, are depressed areas, frequently in floodplains, that slow the runoff's travel time to the lake, and allow sediments to settle out. Wetlands support aquatic and hydric terrestrial plants that can aid sedimentation and assimilate nutrients. Newly constructed wetlands may have soils capable of adsorbing large amounts of soluble phosphorus (but once the adsorption capacity of the soil is reached, they lose this capability). By increasing the travel time for the runoff to reach the lake, sedimentation occurs in many wetlands. For these and other reasons, such as wildlife habitat benefits, creation of wetlands is being evaluated here as a lake enhancement method.

Currently the Hamilton Lake watershed is about 12% wetlands. These wetlands undoubtedly play an important role in watershed hydrology and soil conservation. Unfortunately Indiana and the rest of the Midwest are losing wetlands to development quite rapidly. A top priority of the watershed residents should be to preserve the existing wetlands for their important contribution to lake water quality protection.

The success of wetlands at storing flood water, removing nutrients and sediments, and supporting wildlife is strongly design dependent. Surface area, average depth, hydraulic loading, incoming suspended sediment, vegetation and other factors affect a wetland's effectiveness. Wile et al. (1985) suggest that hydraulic loading rates of 0.03 cubic feet per second per acre (cfs/ac) will provide maximum treatment efficiencies for municipal wastewaters. Hey and Schaefer (1983) and Striegl (1987) found that a 10.4-acre urban limnetic wetland removed between 91% and 95% of incoming total suspended solids and more than 90% of incoming total phosphorus at a hydraulic loading of 0.08 cfs/ac. Nichols (1983) reviewed the capacity of several temperate wetlands to remove nutrients from secondary wastewater effluent and found that, in general, hydraulic loading rates on the order of 0.005 cfs/ac removed more than 90% of incoming phosphorus, but, at higher rates, like 0.25 cfs/ac, removal fell to 60% or less.

Wetland morphology is an important determinant of effectiveness. Deeper wetlands have higher hydraulic retention times and hence higher sedimentation rates, but there is less opportunity for nutrient reaction with wetland soils, the primary nutrient removal mechanism. Richardson (1985) found that phosphorus retention by wetlands can be predicted solely by knowing the extractable aluminum content of the soil; when the wetland soil's phosphorus adsorption capacity is reached, the wetland will become a net exporter of phosphorus. To renew a wetland's phosphorus removal capability, periodic exposure of virgin soils, or addition of P-adsorbing material, will be necessary. Benndorf and Putz (1987) studied the efficiency of pre-dams (check dams upstream of main dam) at removing phosphorus and found these small impoundments rather inefficient, but they recommended them because of their rather low operating costs. During the design phase for detention facilities or wetlands, we recommend that separate compartments be included for sedimentation and nutrient removal as much as possible.

With hydraulic design loadings of 0.05 cfs/ac, the three major tributaries (Black, Jackson-Judson, and an unnamed tributary from the northwest) would require the detention facility/wetland areas shown in Table 18 for their respective subbasins.

Table 18

DETENTION/WETLAND AREA (acres)
FOR MAJOR SUBBASINS OF HAMILTON LAKE

Tributary	Facility Area
Black Creek	150
Jackson-Judson Creek	20
Unnamed Creek from NW	23

Based upon topography, required area, and land uses, eight potential wetland sites were identified in the watershed. Five sites were identified in the Black Creek subbasin. Sedimentation was investigated for the eight wetland sites; the wetlands would reduce sediment discharge to Hamilton Lake by about 30%.

For each site, pond sedimentation was calculated based mainly on estimated sediment yield and trap efficiency (Table 19). Figure 11 shows the estimated sediment yield curve, comprising suspended sediment plus bedload, in tons per square mile per year, versus net drainage area (i.e., excluding the lake itself). From one square mile, for example, the yield is about 900 tons annually, keeping in mind that the yields are long-term averages and that yield in any one year may vary significantly from the average.

The sediment yield curve is based on reservoir, lake, and pond sediment surveys for eleven sites within about 50 miles of Hamilton Lake and drainage areas of less than 50 square miles (USDA 1978). The sites are in Ohio and Michigan, 32 to 58 miles from the study area. Sediment yield is independent of the type of lake the sediment enters. Sediment inflows were computed from the measured sediment deposition rates using Brune's trap efficiency curves for fine sediment or median conditions (ASCE 1975); eight of the reservoirs' deposits had dry specific weights of only 23 to 54 lbs/cubic foot, which indicate mostly fine materials of clay and silt (such as we found at the mouth of

Black Creek) . There is no significant difference in trap efficiencies for normally ponded man-made lakes and natural lakes (not including wetlands). The data points indicated a significant scatter. A least-squares fit of the points provided unrealistic sediment yeilds for the size of the areas above the project ponds. Thus, the slope of the line was fixed at the typical value of -0.12 (ASCE 1975), and because 61% of the watershed above Hamilton Lake has highly erodible soils, the curve was drawn biased towards the upper points.

Trap efficiency for the wetlands, which would behave similar to dry reservoirs, was estimated using the approximate wetlands curve in Figure 12. The curve was derived from data for dry reservoirs (Roehl and Holeman 1973; USDA 1978), two semi-dry reservoirs (Brune 1988), and one wetland (Martin 1988). The curve was drawn parallel to the modified minimum Brune curve (Linsley et al. 1982) to split the data points and fall somewhat below the small-capacity/inflow ratio, wetland point. That point is uncertain because it is based on the reported suspended solids trap efficiency for storm events of 44 to 54 percent, and its capacity and inflow are approximate (USGS 1966).

Capacities of the project ponds were estimated as forty percent of the product of surface area (acres) and maximum depth (feet). Inflow to the ponds was computed as the product of 622 ac-ft/sq mi and the net drainage area; that inflow rate was average streamflow at the US Geological Survey gage on Fish Creek at Hamilton during its period of record through 1984.

As shown on Table 19, pond deposition was usually computed as the product of sediment yield, net drainage area (equalling sediment discharge), and trap efficiency. Sediment discharge at each of the two sites downstream of others, sites E and G, was computed as sediment outflow from the upstream wetland site(s) times a delivery ratio, plus discharge from the intervening drainage area. Delivery ratio was calculated from the drainage areas and the sediment yield curve. Volume of deposition was computed as its weight divided by initial unit weight (based on the sample taken in Hamilton Lake and unit weights for sand, silt, and clay (USBR 1987), and whether the pond was downstream of other wetland sites).

The effectiveness of the wetlands is indicated by comparing their sediment discharges to Hamilton Lake with current sediment discharges. Under existing conditions, sediment discharge to the lake is estimated at 9,000 tons annually (Table 20). With the eight wetlands studied herein being constructed, sediment discharge would be about 6,300 tons annually. The reduction from existing conditions would be 2,700 tons each year, or 30%.

Also for comparison, the size of a single, normally ponded reservoir at site E was estimated which would limit sediment outflow to the same amount as with the five Black Creek sites (A - E). The equivalent reservoir would have a volume of about 160 ac-ft, a surface area of about 26 acres and depth at the dam of 15 feet. The normal reservoir elevation, 940 ft msl, would be about three feet higher than that of the flooded wetland at E; flood surcharge for this reservoir would add a few more feet.

For cost estimating purposes, we assumed that there are basically two general sizes of sediment traps: the smaller one is five to eight feet deep, and the larger one is 12 to 13 feet deep. Other assumptions include:

1. Each site requires an earth embankment and an overflow weir, similar to the facility shown in Figure 13, or, a steel sheetpile of similar geometry;

2. Small ponds have an embankment six feet high and 100 feet long. Side slopes are 2.5 to 1. Crest width is 8 feet. Weir length is 25 feet.

3. Large ponds have an embankment 12 feet high and 300 feet long. Side slopes are 2.5 to 1. Crest width is 8 feet. Weir length is 50 feet.

4. Each wetland will have earth baffles equal in length to five time the dam length. Side slopes are 2 to 1. Crest width is zero.

Costs for construction of a small wetland/sediment trap are given in Table 22, and including a contingency, total $22,000. Costs for construction of a large wetland are detailed in Table 23, and total $130,000. Material quantities are also given in Tables 22 and 23. Assuming sites D, E, and F to be large wetlands, and the other five to be small wetlands, total construction cost will be around $500,000.

After ten years, the wetlands would still have more than 90% of their design capacity (Table 24). Although the wetlands sediment trap efficiencies would not be substantially decreased to the point of requiring restoration (or sediment removal), costs for re-excavation to design capacity are substantial, and for all eight sites total about $230,000 after ten years (Table 24).

Wetland creation is not without adverse environmental impacts. Eight wetland sites have been identified in this study. Each impounds a stream and will change the existing land use from primarily wetland and cropland to wetland. Cropland is taken out of production. Flowing streams and their associated lotic biota are altered. Overall however these ecological impacts are minor, and largely acceptable to regulatory agencies due to the expected improvement in lake water quality, wildlife habitat, and soil conservation. Also, many of the identified wetland sites are on streams considered to be regulated drains by the County Board, and, hence, the County Surveyor must be consulted early during the design studies. Environmental and permitting studies should also be included during the design phase, namely:

- Survey of the sites for threatened and endangered species and cultural resources
- Identification of permits required for construction
- Computation of the structures' required capacity for passing floodwaters

Additionally, several other tasks will be necessary for design:

- Land survey and soil borings at each site
- Collection of storm waters for performance of column settling test (i.e. - determination of sediment particle settling velocity)
- Discussions with the land owners of each site
- Design-level computation of material quantities and cost estimates; preparation of drawings and contract documents

Recommendations for Implementation

Recomendation are outlined below for the enhancement of Hamilton Lake. Priority should be given to watershed control. When watershed controls are well underway, the Lake Association can then turn its resources to inactivating lake phosphorus.

Macrophyte Control. Based upon the above studies of aquatic weed control, harvesting is recommended for future management of the lake's weed problem. A continuation of the herbicide application program is recommended only if the Lake Association unable to implement a weed harvesting program, either by contract harvesting or by purchase and operation of a harvester. Herbicides should only be applied in areas inaccessible to a harvester, where weed control is desired.

Watershed Control. The Lake Association should apply to the "T by 2000" program for design and implementation assistance for construction of wetlands on all tributaries to Hamilton Lake.

Preliminary siting and estimating studies indicate that eight wetlands in the watershed will reduce mean annual sedimentation in the lake by 30%.

Watershed residents should also seek the technical assistance of the Soil and Water Conservation District for implementing BMPs on their land. Cost sharing programs are also available.

Phosphorus Control. After implementation of watershed control programs, the Lake Association should pursue implementation of a phosphorus inactivation project. Alum application will produce significant improvements in water clarity for at least five years. No investments are recommended in phosphorus inactivation until a watershed management and runoff control program has been implemented.

Table 15

ALTERNATIVES FOR CONTROLLING AQUATIC MACROPHYTES IN HAMILTON LAKE

Method	Description	Suitability
Water Level Fluctuations	Exposes sediments to prolonged freezing and drying, killing roots and some species' seed. Submerges & kills some species.	No mechanism currently exists at outlets for significantly lowering water level; can have adverse effects on fisheries, shoreline stability, and riparian structures.
Lake Shading	Dyes and water surface covers can shade and kill many plants.	Not suitable for large lake areas. Water surface covers, like black plastic, may be suitable for small, localized areas.
Phytophagous Fishes	Grass carp and other exotic plant-eating fishes can control some macrophytes.	Not legal in Indiana; can have adverse environmental impacts. Consider in the future if legalized.
Insects	Insects consume plants.	Technology poorly developed for northern climes.
Plant Pathogens	Microorganisms introduced to lake cause diseases in macrophytes.	Technology undeveloped.

Harvesting	Cutting and removing plants by mechanical means.	Requires repeated treatments; technology well developed.
Herbicides	Use of selected chemicals to control plants.	Short-term effectiveness; technology well established.

Table 16

ALTERNATIVES FOR REDUCING PHOSPHORUS LOADINGS IN HAMILTON LAKE

Method	Description	Suitability
Hypolimnetic Withdrawal	Nutrient-rich hypolimnetic water discharged from the lake during stratification, resulting in a net annual loss of P from the system.	No mechanism currently exists at outlet for deep water withdrawal; siphoning or pumping possible but inefficient. Technique is poorly documented. Downstream water quality impacts.
Nutrient Diversion	Diverting incoming P-rich waters to another basin or downstream of lake.	Not suitable for nonpoint sources in Hamilton Lake watershed.
Dilution or Flushing of Nutrients	Diluting lake with large volumes of nutrient-poor water.	No suitable water supply.
Lake Phosphorus Inactivation	Chemical binding of sediment phosphorus by Al salts.	Well tested; especially effective in lakes with high internal phosphorus loadings and low external loadings.
Sediment Oxidation	Adding a reducing agent, like nitrate, to organic-rich sediment prevents hypolimnetic anoxia and sediment P release.	Effective, but not well tested, and must be repeated annually or biannually.

Sediment Removal	Dredging removes the source of internally loaded P and increases depth, greatly reducing the likelihood of recurring weed problems.	Suitable, frequently recommended, but costs are high.
Hypolimnetic Aeration	Oxygenation of hypolimnion prevents sediment release of phosphorus.	May be effective at reducing P recycling, but operating costs can be high.
Wetland Creation	Functions as trap for particle-bound phosphorus, and as a biological treatment basin.	Effectiveness is design-dependant. Early years wetlands are more effective than later. Maintenance may be required.
Artificial Circulation	Eliminates thermal stratification and aerates lake, using air bubbles or mechanical mixers.	Generally used to restore eutrophic lakes having plankton or metal (Fe, Mn) problems rather than for macrophyte control. Operating costs can be high.

Table 19

AVERAGE ANNUAL WETLAND SEDIMENTATION

	Site							
	A	B	C	D	E	F	G	H
Area, ac	32	21	61	36	22	7	13	30
Maximum depth, ft	5	7	5	12	12	13	8	5
Net drainage area, mi^2	1.47	1.0	0.69	0.47	3.87 int	0.20	1.10 int	0.62
Sediment yield, $tons/mi^2$	850	890	930	970	750 int	1100	880 int	940
Sediment discharge, tons	1,240	890	640	460	3,900 total[a]	210	990 total[b]	580
Capacity, ac-ft	64	59	120	170	110	36	42	60
Inflow, ac-ft/yr	910	620	430	290	4,800	120	810	390
Capacity/inflow ratio	0.070	0.095	0.28	0.59	0.023	0.30	0.052	0.15
Trap efficiency, %	52	59	79	84	26	80	44	70
Sediment deposition, tons	650	520	500	380	1,010	170	440	410
Sediment deposition yd^3 [c]	720	570	550	420	1,250	190	500	450
Sediment outflow, tons	590	370	140	80	2,890	40	550	170

[a] 2,900 from intervening area, plus 1,200 outflow X 0.84 from A - D.
[b] 960 from intervening area, plus 40 outflow X 0.71 from F.
[c] Unit weight 67 lb/ft^3 in upstream ponds, 65 in G, and 60 in E.

Table 20

AVERAGE ANNUAL SEDIMENT DISCHARGE
TO HAMILTON LAKE UNDER PRESENT CONDITIONS

Net drainage area, in square miles	14.0
Sediment yield, in tons/square mile	650
Sediment discharge, in tons	9,000

Table 21

AVERAGE ANNUAL SEDIMENT DISCHARGE TO HAMILTON LAKE
WITH ALL EIGHT WETLANDS DEVELOPED

Net drainage area, in square miles	14.0
- Intercepted by wetlands, total	9.8
- Intervening	4.2
Sediment outflow from upstream sites E, G, and H, in tons	3,600
Delivery ratio	0.89
Sediment discharge to Hamilton Lake from upstream sites, in tons	3,200
Intervening area sediment yield, in tons per square mile	750
Intervening area sediment discharge, in tons	3,100
Total sediment discharge to the lake, in tons	6,300

Table 22

CONSTRUCTION COSTS FOR A SMALL WETLAND

Item and Quantity	Cost
Dam (255 cy @ $10/cy)	$2,550
Baffles (230 cy @ $10)	2,300
Seeding/Reclamation (820 sy @ $2/sy)	1,640
Gravel (15 cy @ $20)	300
Excavation (50 cy @ $15/cy)	750
Concrete (20 cy @ $400/cy)	8,000
Riprap (10 cy @ $25/cy)	250
Mobilization (ls)	1,000
Subtotal	$16,790
Contingency (@ ~30%)	5,210
TOTAL	$22,000

Table 23

CONSTRUCTION COSTS FOR A LARGE WETLAND

Item and Quantity	Cost
Dam (2,800 cy @ $10/cy)	$28,000
Baffles (2,800 cy @$10/cy)	28,000
Seeding/Reclamation (4,700 sy @ $2/sy)	9,400
Gravel (45 cy @ $20/cy)	900
Excavation (185 cy @ $15/cy)	2,775
Concrete (70 cy @ $400/cy)	28,000
Riprap (30 cy @ $25/cy)	750
Mobilization (ls)	2,000
Subtotal	$99,825
Contingency (@ ~30%)	30,175
TOTAL	$130,000

Table 24

SEDIMENT DEPOSITION OVER A TEN YEAR PERIOD
AND THE COST FOR RESTORING THE SEDIMENT TRAPS TO ORIGINAL CAPACITY

	Site A	B	C	D	E	F	G	H	Total
Inflow (ac-ft/yr)	910	620	430	290	4800	120	810	390	
Year 0 Capacity (ac-ft)	64	59	120	170	110	36	42	60	
Year 0 Capacity/inflow ratio	0.070	0.095	0.279	0.586	0.023	0.300	0.052	0.154	
Year 1 Deposition (cu yds)	720	570	550	420	1250	190	500	450	4,650
Year 1 Capacity (ac-ft)	63.6	58.6	119.7	169.7	109.2	35.9	41.7	59.7	
Year 1 Capacity/inflow ratio	0.070	0.095	0.278	0.585	0.023	0.299	0.051	0.153	
Year 2 Capacity (ac-ft)	63.1	58.3	119.3	169.5	108.5	35.8	41.4	59.4	
Year 2 Capacity/inflow ratio	0.069	0.094	0.277	0.584	0.023	0.298	0.051	0.152	
Year 3 Capacity (ac-ft)	62.7	57.9	119.0	169.2	107.7	35.6	41.1	59.2	
Year 3 Capacity/inflow ratio	0.069	0.093	0.277	0.584	0.022	0.297	0.051	0.152	
Year 4 Capacity (ac-ft)	62.2	57.6	118.6	169.0	106.9	35.5	40.8	58.9	
Year 4 Capacity/inflow ratio	0.068	0.093	0.276	0.583	0.022	0.296	0.050	0.151	
Year 5 Capacity (ac-ft)	61.8	57.2	118.3	168.7	106.1	35.4	40.5	58.6	
Year 5 Capacity/inflow ratio	0.068	0.092	0.275	0.582	0.022	0.295	0.050	0.150	
Year 6 Capacity (ac-ft)	61.3	56.9	118.0	168.4	105.4	35.3	40.1	58.3	
Year 6 Capacity/inflow ratio	0.067	0.092	0.274	0.581	0.022	0.294	0.050	0.150	
Year 7 Capacity (ac-ft)	60.9	56.5	117.6	168.2	104.6	35.2	39.8	58.0	
Year 7 Capacity/inflow ratio	0.067	0.091	0.274	0.580	0.022	0.293	0.049	0.149	
Year 8 Capacity (ac-ft)	60.4	56.2	117.3	167.9	103.8	35.1	39.5	57.8	
Year 8 Capacity/inflow ratio	0.066	0.091	0.273	0.579	0.022	0.292	0.049	0.148	
Year 9 Capacity (ac-ft)	60.0	55.8	116.9	167.7	103.0	34.9	39.2	57.5	
Year 9 Capacity/inflow ratio	0.066	0.090	0.272	0.578	0.021	0.291	0.048	0.147	
Year 10 Capacity (ac-ft)	59.5	55.5	116.6	167.4	102.3	34.8	38.9	57.2	
Year 10 Capacity/inflow ratio	0.065	0.089	0.271	0.577	0.021	0.290	0.048	0.147	
Total Deposition (cu yds)	7,200	5,700	5,500	4,200	12,500	1,900	5,000	4,500	46,500
% Original Capacity	93%	94%	97%	98%	93%	97%	93%	95%	
Restoration Cost	$36,000	$28,500	$27,500	$21,000	$62,500	$9,500	$25,000	$22,500	$232,500

Notes on Assumptions: 1. Constant rate of deposition. This results in slightly overestimated sediment accumulation, and therefore, restoration costs.
2. Dredging units cost of $5/cubic yard in year 10.

Table 25

COMPARISON OF ALTERNATIVES EVALUATED AT THE THIRD LEVEL OF STUDY

Alternative	Cost	Comment
Weed Harvesting	$135,000 in first year; $45,000 in later years	Requires annual harvesting; nutrients and organic matter are removed from the system. Will produce long-term gains in water clarity
Herbicides	$18,200 in 1989 was spent by Lake Association; will increase in succeeding years	No restorative benefits; herbicide application is only appropriate for localized areas inaccessible to harvester, such as marinas or boat docks
Phosphorus Inactivation	$390,000	Effectiveness up to 5 years or more, depending upon external loadings; is appropriate only after watershed loading is addressed
Hypolimnetic Aeration	$2,300,000	High capital and recurring costs; additional data required for design of system
Artifical Circulation	similar to hypolimnetic aeration	High capital and recurring costs; additional data required for design of system

Wetlands	$500,000 for eight sites	Reduction in sediment loading of 30%; comparable reduction in phosphorus loading; >90% capacity retained after 10 years

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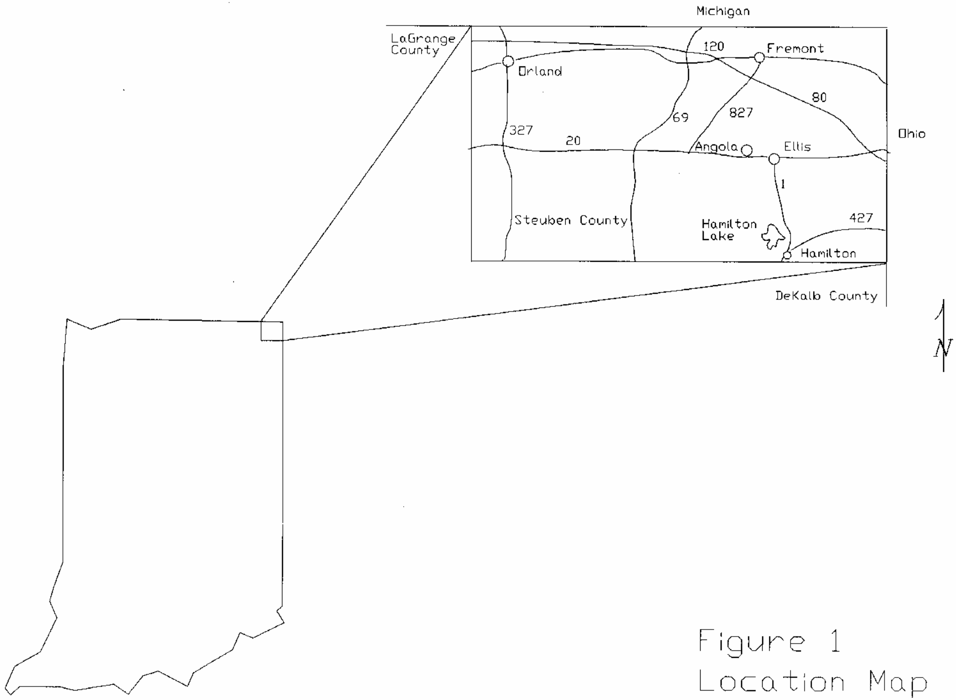

Figure 1
Location Map

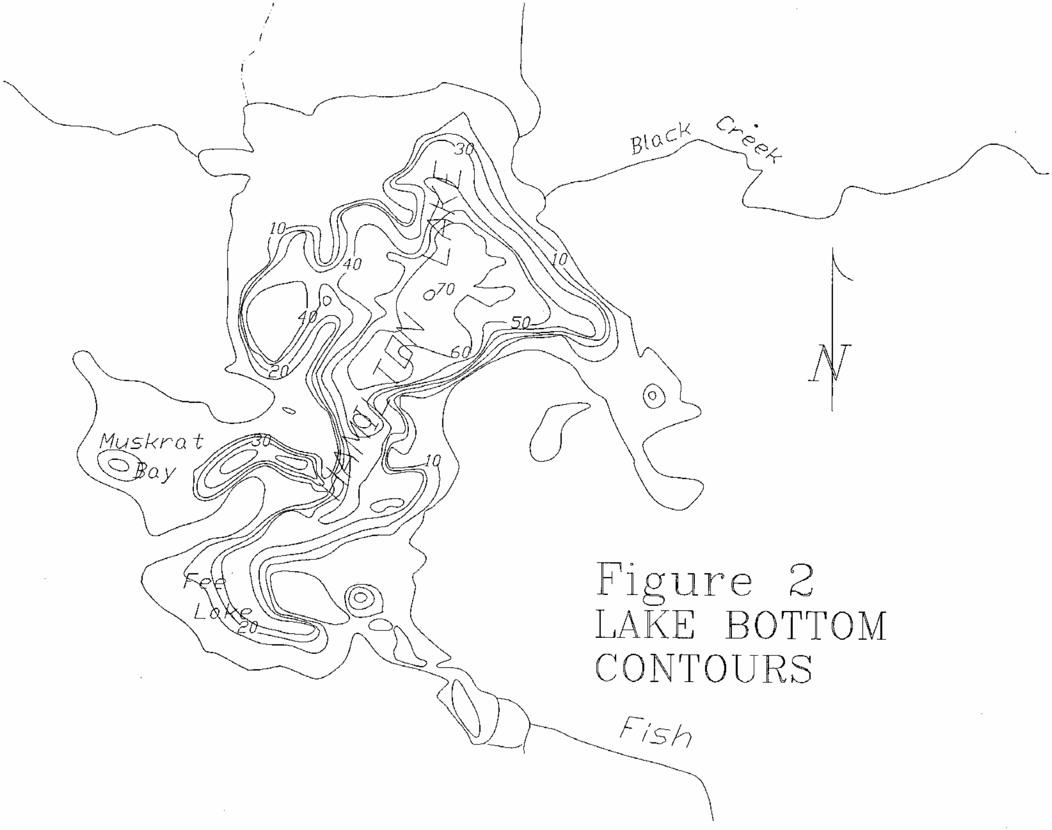

Figure 2
LAKE BOTTOM
CONTOURS

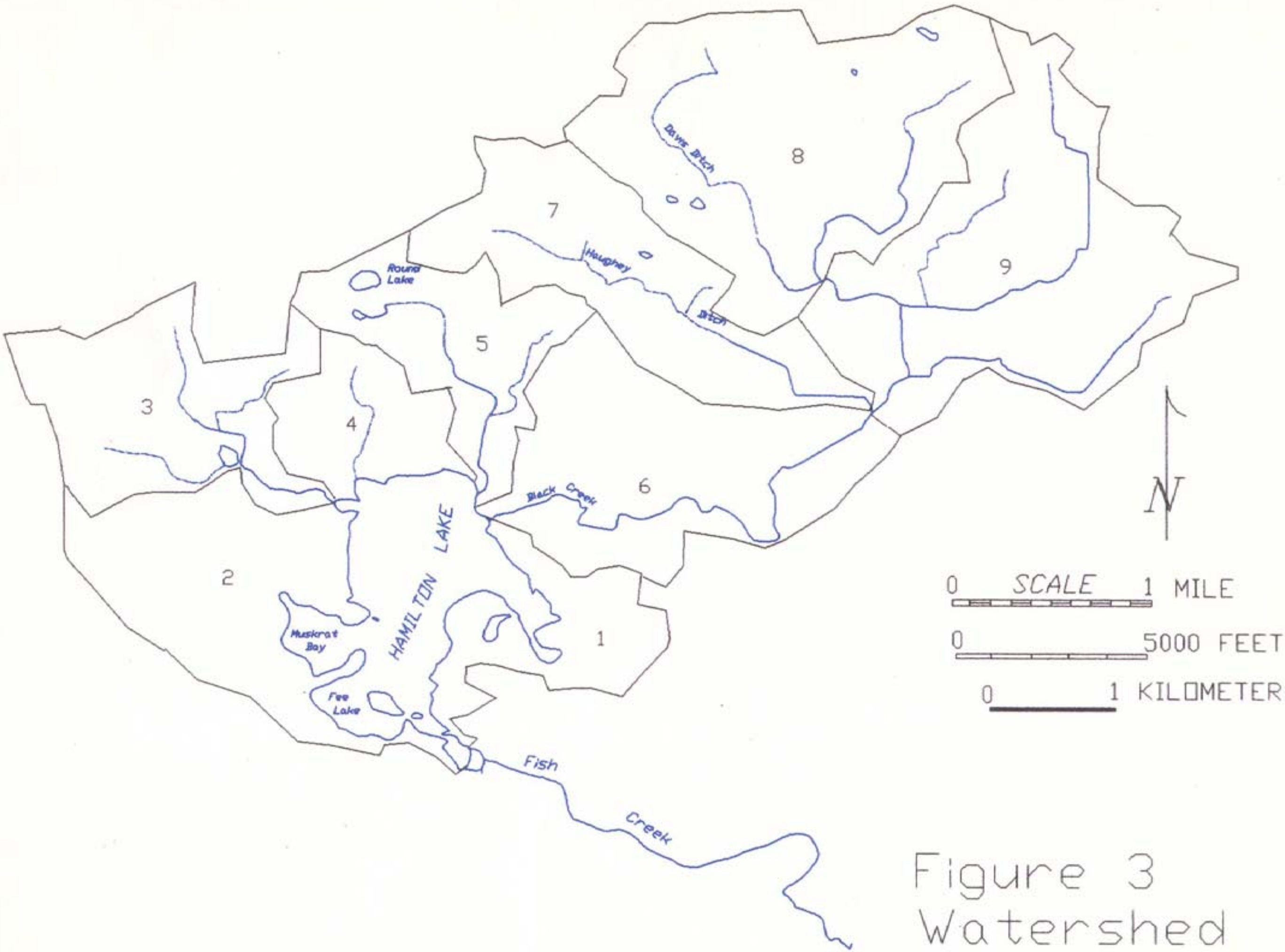

Figure 3
Watershed

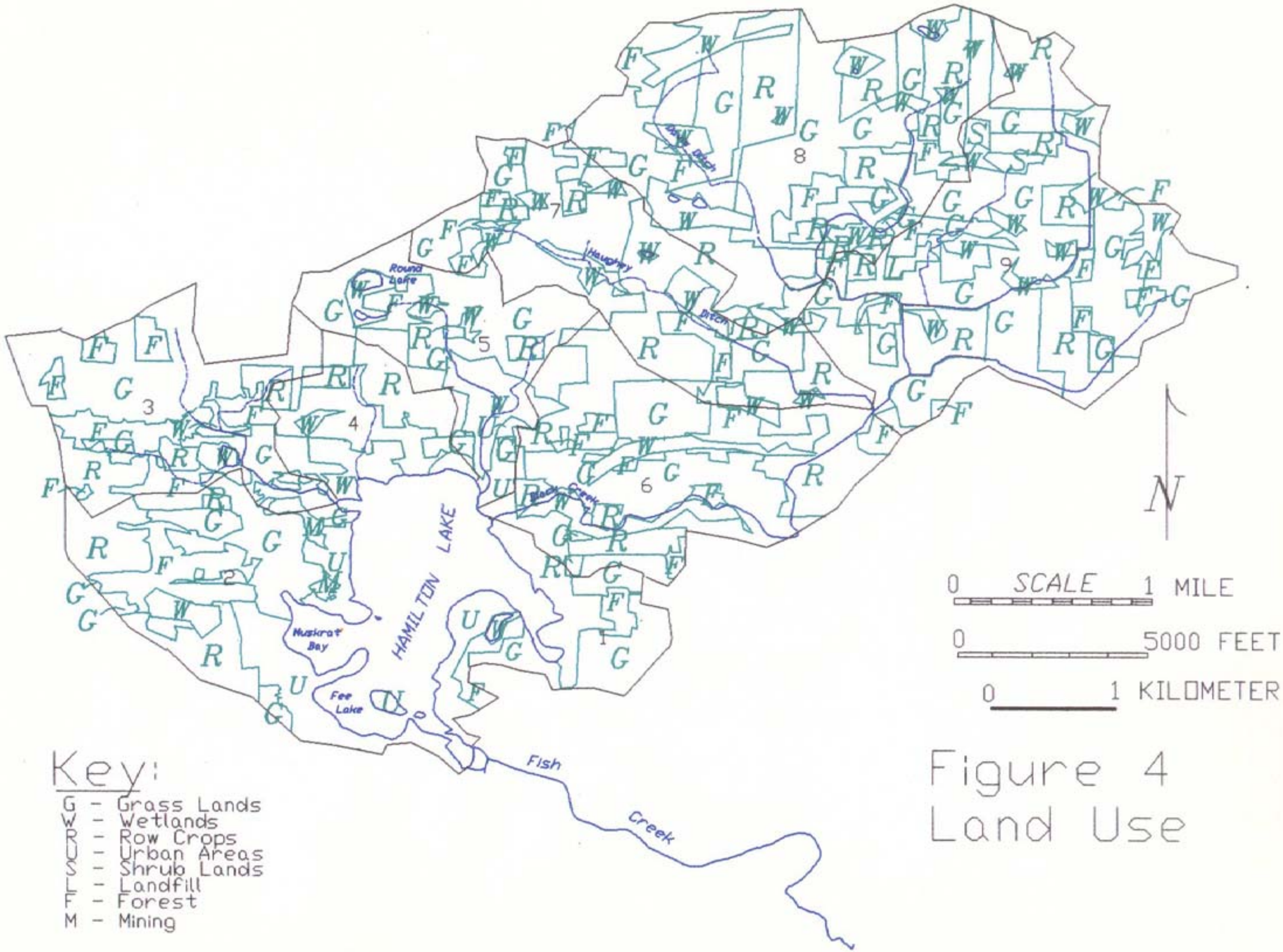

Figure 4
Land Use

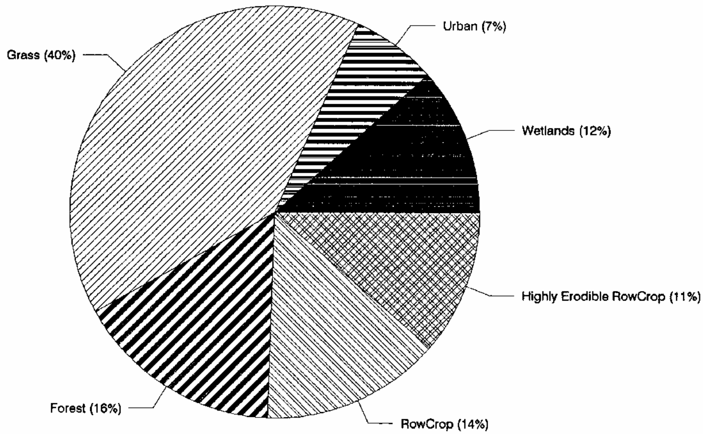

Figure 5
LAND USE IN THE WATERSHED

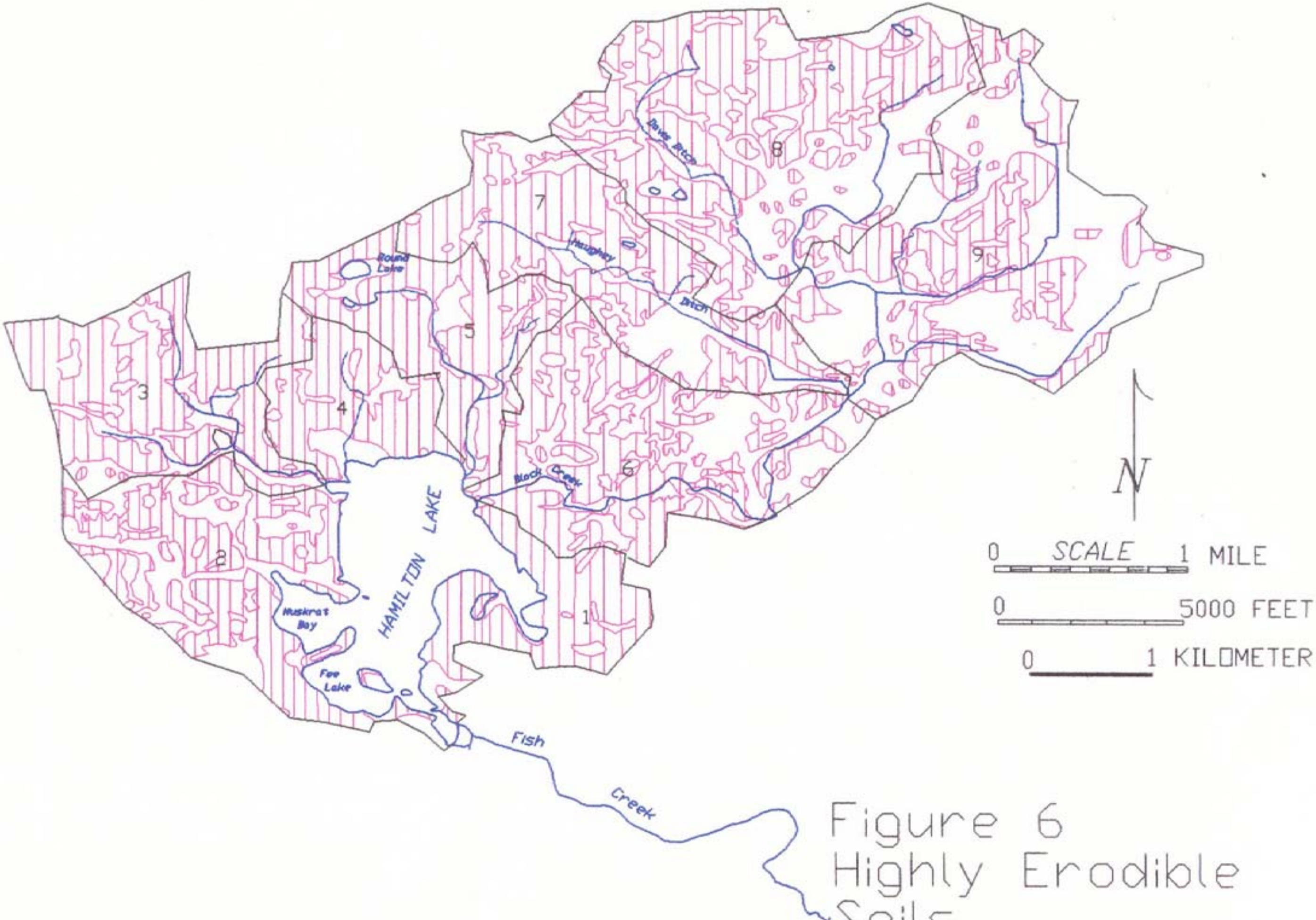

Figure 6
Highly Erodible Soils

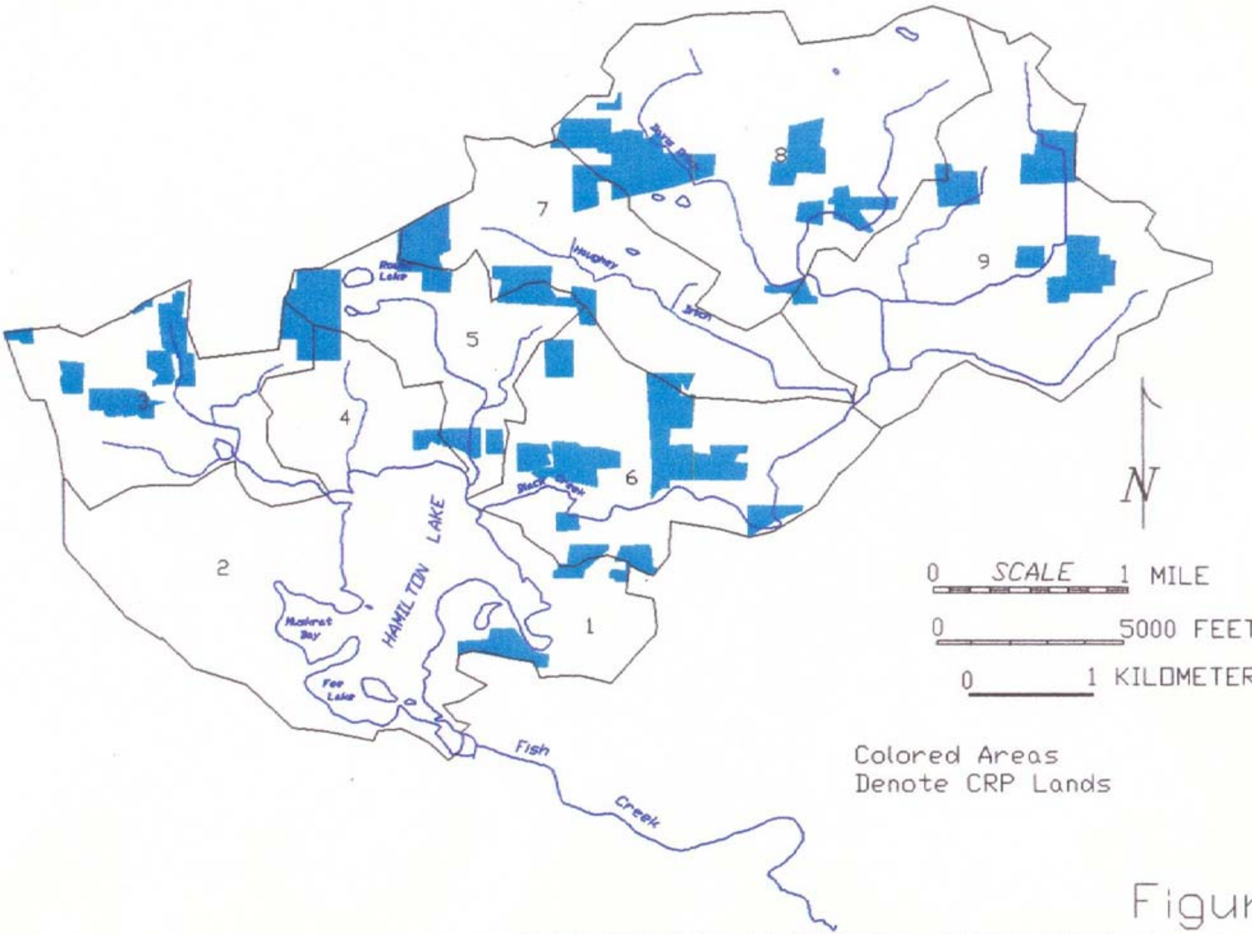

Figure 7
CONSERVATION RESERVE LANDS

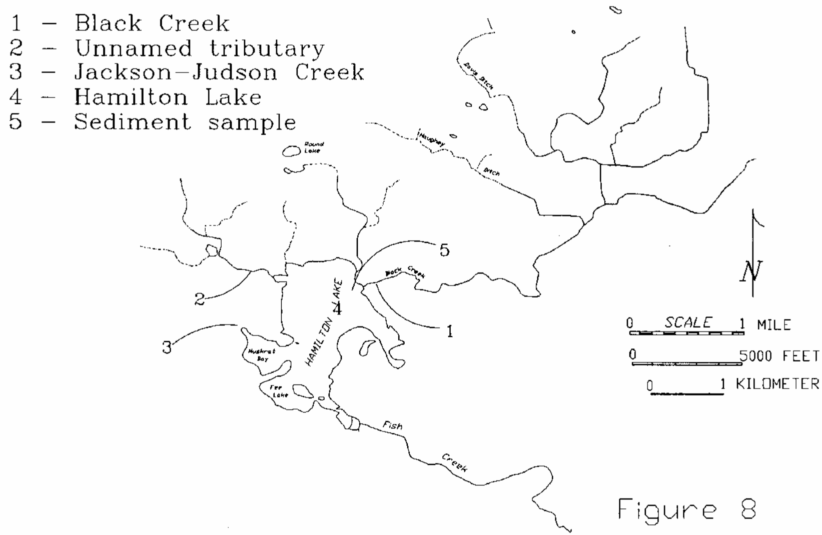

Figure 8
SAMPLING LOCATIONS

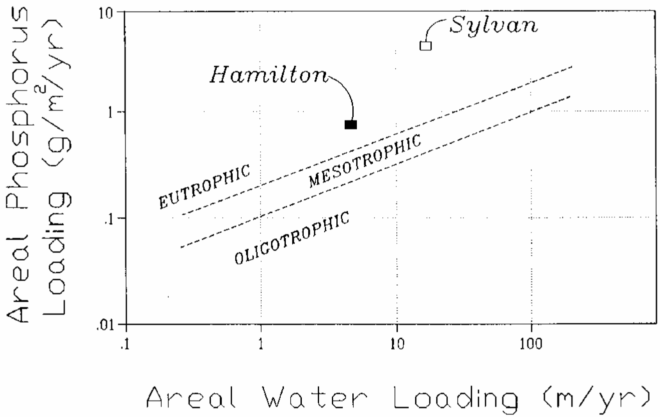

Figure 9
VOLLENWEIDER'S LOADING PLOT

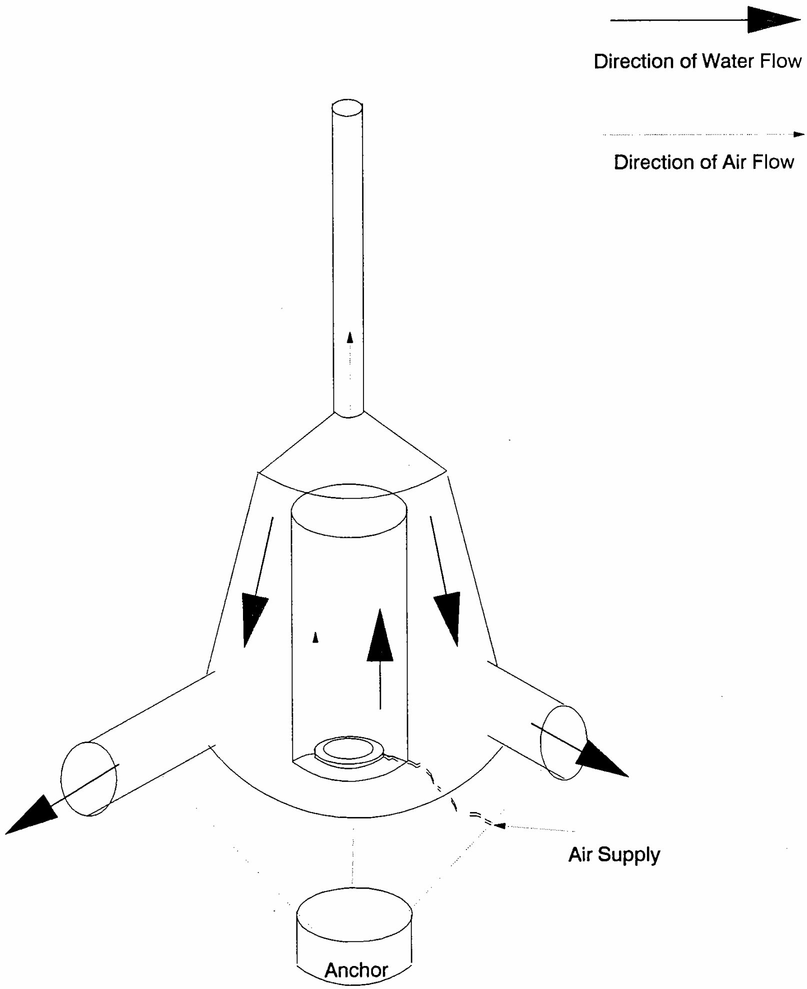

Figure 10
PARTIAL AIR-LIFT AERATION SYSTEM

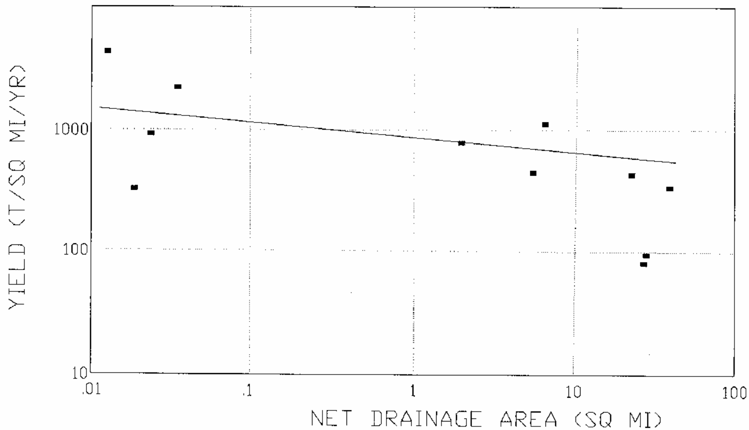

Figure 11
SEDIMENT YIELD,
HAMILTON LAKE REGION

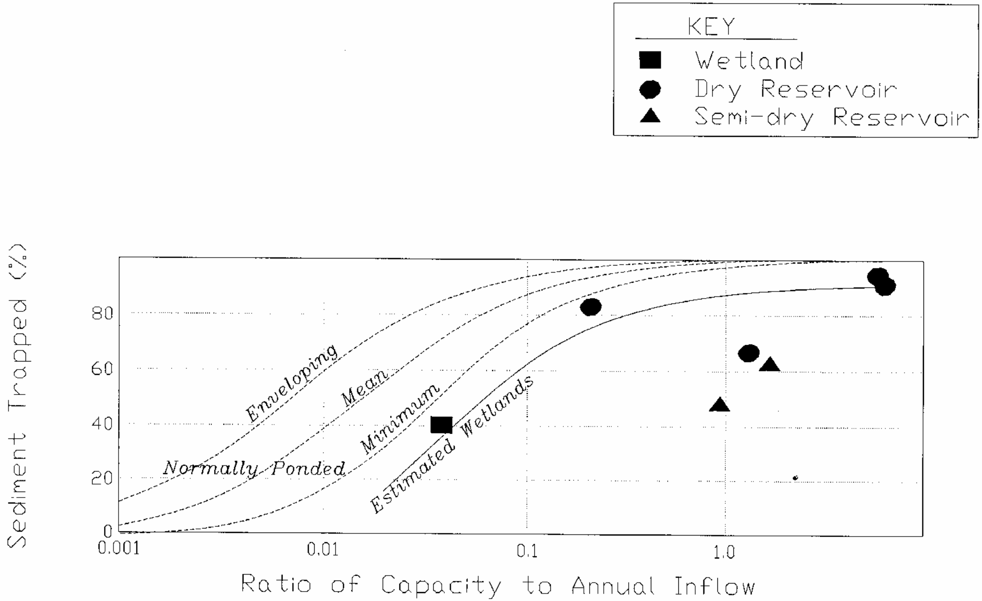

Figure 12
RESERVOIR TRAP EFFICIENCY

Figure 13
TYPICAL CONSTRUCTED WETLAND
OVERFLOW STRUCTURE

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ANALYTICAL REPORT

Mr. David Pott
HARZA ENGINEERING CO.
150 So. Wacker Drive
Chicago IL 60606

08-11-89

Sample No.: 86951

Sample Description: Mouth Of Black Creek
Hamilton Lake Study

Date Taken: 07-27-89 1430

Date Received: 07-28-89 1110

BOD - Five Day	3.	mg/L
Nitrogen, Ammonia	0.28	mg/L
Nitrogen, Nitrate	1.24	mg/L
Nitrogen, Nitrite	0.05	mg/L
Nitrogen, Organic	2.02	mg/L
Phosphate Ortho Dissolved	0.12	mg/L
Phosphorus, Total	0.04	mg/L
Solids, Suspended	12.	mg/L
Coliform, Fecal	5300.	/100 mL
Streptococcus	90.	/100 mL

Lorrie Krebs

Lorrie Krebs
Project Manager

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Bartlett Division
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ANALYTICAL REPORT

Mr. David Pott
HARZA ENGINEERING CO.
150 So. Wacker Drive
Chicago IL 60606

09-06-89

Sample No.: 87279

Sample Description: #1; Composite
Hamilton Lake

Date Taken: 08-01-89 1143

Date Received: 08-02-89 0900

Nitrogen, Ammonia	0.29	mg/L
Nitrogen, Kjeldahl	0.50	mg/L
Nitrogen, Nitrate	<0.01	mg/L
Nitrogen, Nitrite	<0.01	mg/L
pH	7.55	units
Phosphate Ortho Dissolved	0.03	mg/L
Phosphorus, Total	0.05	mg/L
Solids, Suspended	2.	mg/L
Coliform, Fecal	16.	/100 mL
Streptococcus	0.	/100 mL
Chlorophyll a	0.011	mg/L
Pheophytin	0.015	mg/L

W. Mottashed
William H. Mottashed
Division Manager

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ANALYTICAL REPORT

Mr. David Pott
HARZA ENGINEERING CO.
150 So. Wacker Drive
Chicago IL 60606

09-06-89

Sample No.: 87280

Sample Description: #2; Lake-Epilimnion
Hamilton Lake

Date Taken: 08-01-89 1126

Date Received: 08-02-89 0900

Nitrogen, Ammonia	0.24	mg/L
Nitrogen, Kjeldahl	0.45	mg/L
Nitrogen, Nitrate	<0.01	mg/L
Phosphorus, Total	0.03	mg/L
Solids, Suspended	5.	mg/L

W. Mottashed
William H. Mottashed
Division Manager

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ANALYTICAL REPORT

Mr. David Pott
HARZA ENGINEERING CO.
150 So. Wacker Drive
Chicago IL 60606

09-06-89

Sample No.: 87281

Sample Description: #3; Lake-Hypolimnion
Hamilton Lake

Date Taken: 08-01-89 1130

Date Received: 08-02-89 0900

Nitrogen, Ammonia	0.33	mg/L
Nitrogen, Kjeldahl	0.78	mg/L
Nitrogen, Nitrate	<0.01	mg/L
Nitrogen, Nitrite	<0.01	mg/L
Phosphorus, Total	0.10	mg/L
Solids, Suspended	6.	mg/L

W. Mottashed
William H. Mottashed
Division Manager

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ANALYTICAL REPORT

Mr. David Pott
HARZA ENGINEERING CO.
150 So. Wacker Drive
Chicago IL 60606

09-06-89

Sample No.: 87282

Sample Description: #4; Jackson Judson Creek
Hamilton Lake

Date Taken: 08-01-89 0740

Date Received: 08-02-89 0900

Nitrogen, Ammonia	0.17	mg/L
Nitrogen, Kjeldahl	0.25	mg/L
Nitrogen, Nitrate	0.55	mg/L
Nitrogen, Nitrite	0.05	mg/L
Phosphate Ortho Dissolved	0.18	mg/L
Phosphorus, Total	0.07	mg/L
Solids, Suspended	8.	mg/L
Coliform, Fecal	110.	/100 mL
Streptococcus	127.	/100 mL

W. Mottashed
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ANALYTICAL REPORT

Mr. David Pott
HARZA ENGINEERING CO.
150 So. Wacker Drive
Chicago IL 60606

09-07-89

Sample No.: 87283

Sample Description: #5; Unnamed Trib
Hamilton Lake

Date Taken: 08-01-89 1500

Date Received: 08-02-89 0900

Nitrogen, Ammonia	0.36	mg/L
Nitrogen, Kjeldahl	0.54	mg/L
Nitrogen, Nitrate	<0.01	mg/L
Nitrogen, Nitrite	<0.01	mg/L
Phosphate Ortho Dissolved	0.28	mg/L
Phosphorus, Total	0.13	mg/L
Solids, Suspended	19.	mg/L

W. Mottashed
William H. Mottashed
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ANALYTICAL REPORT

Mr. David Pott
HARZA ENGINEERING CO.
150 So. Wacker Drive
Chicago IL 60606

09-07-89

Sample No.: 87284

Sample Description: #6; Black Creek
Hamilton Lake

Date Taken: 08-01-89 1520

Date Received: 08-02-89 0900

Nitrogen, Ammonia	0.38	mg/L
Nitrogen, Kjeldahl	0.50	mg/L
Nitrogen, Nitrate	0.38	mg/L
Nitrogen, Nitrite	0.02	mg/L
Phosphate Ortho Dissolved	0.09	mg/L
Phosphorus, Total	0.07	mg/L
Solids, Suspended	6.	mg/L
Coliform, Fecal	100	/100 mL
Streptococcus	46.	/100 mL

W. Mottashed

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ANALYTICAL REPORT

Mr. David Pott
HARZA ENGINEERING CO.
150 So. Wacker Drive
Chicago IL 60606

09-07-89

Sample No.: 87285

Sample Description: Sediment; Lake Black Creek Mouth Hamilton Lake

Date Taken: 08-01-89 1250

Date Received: 08-02-89 0900

Phosphorus, Total	306.	ug/g
Solids, Total	39.85	%
Water (Karl Fischer)	61.4	%
EP Tox - Arsenic	0.004	mg/L
EP Tox - Barium	0.672	mg/L
EP Tox - Cadmium	<0.005	mg/L
EP Tox - Chromium	0.002	mg/L
EP Tox - Lead	<0.04	mg/L
EP Tox - Mercury	<0.0001	mg/L
EP Tox - Selenium	<0.001	mg/L
EP Tox - Silver	<0.005	mg/L
EP Tox - Endrin	<0.1	ug/L
EP Tox - Lindane	<0.05	ug/L
EP Tox - Methoxychlor	<0.5	ug/L
EP Tox - Toxaphene	<0.5	ug/L
EP Tox - 2,4-D	<2.0	ug/L
EP Tox - 2,4,5-TP	<2.0	ug/L
#100 Sieve	2.52	%
Pan (Fines)	68.73	%
#60 Sieve	12.22	%
#230 Sieve	1.41	%
#200 Sieve	8.56	%
#80 Sieve	6.56	%

Results on a dry weight basis.

W. Mottashed

William H. Mottashed
Division Manager

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☐ 3548 35th St.
Rockford IL 61109
815-874-2171

CHAIN OF CUSTODY RECORD

Client Harza Engineering **Project** Hamilton Lake

Sampler(s) David Pott 855-7075

Number	Sampling Location	Date	Time	Composite	Grab	No. of Bottles	Remarks
1	Lake			X		5	(clean surface water)
2	"				X	5	" " "
3	"				X	5	" " "
4	Jackson Judson Ck				X	5	" " "
5	Unnamed Creek				X	5	" " "
6	Black Creek				X	5	" " "
7	Lake (Black Creek mouth)				X	2	Sediment (clean)

Relinquished By	Received By	Date	Time
David B Pott			

Shipping Notes	Received For Aqualab By	Date	Time
	~~Diane~~ Klein	8/2/89	0900

140

LAKE PHOSPHORUS MODEL
(Based upon Reckhow and Simpson, 1980)

$$P = L/(11.6 + 1.2 * qs)$$

Where: P = Lake phosphorus concentration (mg/L)
L = Phosphorus loading (g/sq m-yr)
qs = Areal water loading (m/yr)

Estimation of qs for Hamilton Lake:

$$Q = (Ad * r) + (Ao * Pr)$$

and

$$qs = Q/Ao$$

Where: Q = Inflow water volume (cu m/yr)
Ao = Lake surface area = 2,990,733 sq m
Ad = Watershed area = 39,211,788 sq m
r = Total annual unit runoff = 0.296 m/yr
Pr = Mean annual net precipitation = 0.901 m/yr

Q =1.43E+07 cu m/yr
qs = 4.78 m/yr

Estimation of L for Hamilton Lake

$$M = (Ef * Af) + (Ea *Aa) + (Ee * Ae) + (Eg * Ag) + (Eu * Au) + (Ew * Aw) + (Ep * Ao) + PSI$$

and

$$L = M / Ao$$

Where: M = Total phosphorus mass loading (kg/yr)
Ef = P export coefficient for forest land (kg/ha-yr)
Af = Area of forest land (ha)
Ea = P export coefficient for rowcrop land (kg/ha-yr)
Aa = Area of rowcrop land (ha)
Ee = P export coefficient for highly erodible rowcrop land (kg/ha
Ae = Area of highly erodible rowcrop land (ha)
Eg = P export coefficient for grass land (kg/ha-yr)
Ag = Area of grass land (ha)
Eu = P export coefficient for urban land (kg/ha-yr)
Au = Area of urban land (ha)
Ew = P export coefficient for wetland (kg/ha-yr)
Aw = Area of wetland (ha)
Ep = P export coefficient for precipitation (kg/ha-yr)
PSI = Point source inputs

Hamilton Lake Phosphorus Model

Sources	Area	Phosphorus Export Coefficients High	Most Likely	Low	
Forest	595 ha	0.2	0.1	0.05	kg/ha-yr
Rowcrop	513	3.0	1.0	0.25	
Erodible	411	6.0	2.5	0.5	
Grass	1428	1.5	0.4	0.05	
Urban	239	1.0	0.6	0.25	
Wetland	429	0.02	-0.2	-0.5	
Mining	8.7	2.0	0.7	0.05	
Shrub	12.9	0.25	0.1	0.07	
Precip	299	0.3	0.2	0.1	
	3935 ha				

	Phosphorus Mass Loading High	Most Likely	Low	
Forest	119	59	29.7	kg/yr
Rowcrop	1538	513	128	
Erodible	2468	1028	206	
Grass	2142	571	71	
Urban	239	143	60	
Wetland	9	-86	-215	
Mining	17	6	0	
Shrub	3	1	1	
Precip	90	60	30	
W =	6,624	2,296	311	kg/yr

Areal Phosphorus Loading (L):

High = 2.2 g/sq m/yr
Most likely = 0.8
Low = 0.10

Lake Phosphorus Concentration (P):

High = 0.128 mg/L
Most likely = 0.044
Low = 0.006

September 18, 1989

ESTIMATION OF UNCERTAINTY (St)

log P (most likely) =	-1.354
"Positive" model error =	0.0152 mg/L
"Negative" model error =	-0.0113 mg/L
"Positive" loading error =	0.0417 mg/L
"Negative" loading error =	0.0191 mg/L
"Positive" uncertainty =	0.0444 mg/L
"Negative" uncertainty =	0.0222 mg/L
55% confidence limits (lower) =	0.022 mg/L
55% confidence limits (upper) =	0.089 mg/L
90% confidence limits (lower) =	-0.0002 mg/L
90% confidence limits (upper) =	0.133 mg/L

Hamilton Lake Phosphorus Model

PHOSPHORUS LOADINGS BY SUBBASIN

Watershed 1

Source	Area (ha)	High	Likely	Low	
Forest	25.8	5	3	1	kg/yr
Rowcrop	0.0	0	0	0	
Erodible	0.3	2	1	0	
Grass	72.4	109	29	4	
Urban	83.5	84	50	21	
Wetland	5.2	0	-1	-3	
Precip	0.0	0	0	0	
	187.3	199	81	23	kg/yr

Watershed 2

Source	Area (ha)	High	Likely	Low	
Forest	71.4	14	7	4	kg/yr
Rowcrop	46.3	139	46	12	
Erodible	42.6	256	107	21	
Grass	97.7	146	39	5	
Urban	110.1	110	66	28	
Wetland	18.1	0	-4	-9	
Mining	8.3	17	6	0	
Precip	299.1	90	60	30	
	693.6	772	327	90	kg/yr

Watershed 3

Source	Area (ha)	High	Likely	Low	
Forest	86.0	17	9	4	kg/yr
Rowcrop	32.7	98	33	8	
Erodible	19.7	118	49	10	
Grass	179.5	269	72	9	
Urban	0.0	0	0	0	
Wetland	27.2	1	-5	-14	
Mining	0.4	1	0	0	
Precip	0.0	0	0	0	
	345.5	504	157	18	kg/yr

Watershed 4

Source	Area (ha)	High	Likely	Low	
Forest	56.1	11	6	3	kg/yr
Rowcrop	46.7	140	47	12	
Erodible	10.6	64	27	5	
Grass	13.4	20	5	1	
Urban	5.7	6	3	1	
Wetland	35.0	1	-7	-18	
Precip	0.0	0	0	0	
	167.6	242	81	4	kg/yr

Watershed 5

Source	Area (ha)	High	Likely	Low	
Forest	19.3	4	2	1	kg/yr
Rowcrop	4.6	14	5	1	
Erodible	26.6	160	66	13	
Grass	139.5	209	56	7	
Urban	16.1	16	10	4	
Wetland	64.2	1	-13	-32	
Precip	0.0	0	0	0	
	270.3	404	126	-6	kg/yr

Watershed 6

Source	Area (ha)	High	Likely	Low	
Forest	62.6	13	6	3	kg/yr
Rowcrop	113.2	340	113	28	
Erodible	28.1	169	70	14	
Grass	190.0	285	76	9	
Urban	23.6	24	14	6	
Wetland	58.5	1	-12	-29	
Precip	0.0	0	0	0	
	476.0	831	268	32	kg/yr

Watershed 7

Source	Area (ha)	High	Likely	Low	
Forest	42.3	8	4	2	kg/yr
Rowcrop	56.8	170	57	14	
Erodible	81.3	488	203	41	
Grass	175.8	264	70	9	
Urban	0.0	0	0	0	
Wetland	47.3	1	-9	-24	
Precip	0.0	0	0	0	
	403.4	931	325	42	kg/yr

Watershed 8

Source	Area (ha)	High	Likely	Low	
Forest	72.4	14	7	4	
Rowcrop	85.8	257	86	21	kg/yr
Erodible	131.4	789	329	66	
Grass	308.6	463	123	15	
Urban	0.0	0	0	0	
Wetland	109.3	2	-22	-55	
Precip	0.0	0	0	0	
	707.6	1526	523	52	kg/yr

Hamilton Lake Phosphorus Model

Watershed 9

Source	Area (ha)	High	Likely	Low	
Forest	158.9	32	16	8	kg/yr
Rowcrop	126.5	380	127	32	
Erodible	70.6	423	176	35	
Grass	250.8	376	100	13	
Urban	0.0	0	0	0	
Wetland	64.2	1	-13	-32	
Shrubs	12.9	3	1	1	
Precip	0.0	0	0	0	
	683.9	1216	408	56	kg/yr

Total Watershed Loadings

Source	Area (ha)	High	Likely	Low	
Forest	594.7	119	59	30	kg/ha
Rowcrop	512.7	1538	513	128	
Erodible	411.3	2468	1028	206	
Grass	1427.7	2142	571	71	
Urban	239.1	239	143	60	
Wetland	429.1	9	-86	-215	
Mining	8.7	17	6	0	
Shrubs	12.9	3	1	1	
Precip	299.1	90	60	30	
	3935	6624	2296	311	kg/ha